MISCELLANEOUS PAPER EL-81-8

SITE CHARACTERIZATION FOR THE MBCE/DIRT II BATTLEFIELD ENVIRONMENT TESTS

by

James B. Mason and Katherine S. Long

Environmental Laboratory
U. S. Army Engineer Waterways Experiment Station
P. O. Box 631, Vicksburg, Miss. 39180

September 1981

Final Report

Approved For Public Release; Distribution Unlimited

Prepared for Army Atmospheric Sciences Laboratory
U. S. Army Development and Readiness Command
White Sands Missile Range, N. Mex. 88002

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
Miscellaneous Paper EL-81-8

2. GOVT ACCESSION NO.
AD-A107 338

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
SITE CHARACTERIZATION FOR THE MBCE/DIRT II BATTLEFIELD ENVIRONMENT TESTS.

5. TYPE OF REPORT & PERIOD COVERED
Final report.

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
James B. Mason
Katherine S. Long

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U. S. Army Engineer Waterways Experiment Station
Environmental Laboratory
P. O. Box 631, Vicksburg, Miss. 39180

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS
U. S. Army Development and Readiness Command
Army Atmospheric Sciences Laboratory
White Sands Missile Range, N. Mex. 88002

12. ~~REPORT DATE~~
Sep[redacted] 1981

13. NUMBER OF PAGES
51

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES
Available from National Technical Information Service, 5285 Port Royal Road, Springfield, Va. 22151.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Environmental analysis
Explosives
Military operations
Munitions
Terrain analysis

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The Munitions Bare Charge Equivalence/Dusty Infrared Test II (MBCE/DIRT II) test series was conducted as a joint field experiment by the Atmospheric Sciences Laboratory and the U. S. Army Engineer Waterways Experiment Station (WES) at White Sands Missile Range, N. Mex., in July 1979. The purpose of the DIRT II portion of the test was to measure the transmission of optical energy through the obscurants generated by explosives interacting with the terrain. This report describes procedures and measurements conducted by the

(Continued)

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

20. ABSTRACT (Continued).

Environmental Laboratory of WES to establish the relevant physical properties of the test site for use in determining the nature and amount of the obscurant material. A portion of this effort was also devoted to the selection and description of a standard set of measurements and sampling procedures for general use in such tests. The resulting set is described along with the rationale behind it.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE(When Data Entered)

PREFACE

The work described herein was sponsored by the Army Atmospheric Sciences Laboratory of the U. S. Army Development and Readiness Command (DARCOM) and was conducted by the Environmental Laboratory (EL) of the U. S. Army Engineer Waterways Experiment Station (WES) under Inter-Army Order No. ASL-79-8116 dated 23 April 1979. The field measurement portion of the work was conducted at White Sands Missile Range, N. Mex., from 17 to 28 July 1979. The laboratory analysis was conducted at WES from 1 August to 31 December 1979.

Site work for this segment of the study was performed by Messrs. Carlos Lebron, Billy Helmuth, and Douglas Rockett under the technical supervision of Mr. James B. Mason, Project Scientist, and Mr. Jerry R. Lundien, Program Manager. At the time all were members of the Environmental Constraints Group, Dr. L. E. Link, Chief, of the Environmental Systems Division, Mr. Bob O. Benn, Chief. Assistance in the soil analysis was provided by the Soil Mechanics Division, Geotechnical Laboratory, WES, and the Concrete Technology Division, Structures Laboratory, WES.

This report was written by Mr. James B. Mason with the assistance of Mrs. Katherine S. Long. The Chief of the EL during this period was Dr. John Harrison.

Commanders and Directors of WES during the test and preparation of this report were COL John L. Cannon, CE, COL Nelson P. Conover, CE, and COL Tilford C. Creel, CE. Technical Director was Mr. Fred R. Brown.

This report should be cited as follows:

> Mason, J. B., and Long, K. S. 1981. "Site Characterization for the MBCE/DIRT II Battlefield Environment Tests," Miscellaneous Paper EL-81-8, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
inches	2.54	centimetres
miles (U. S. statute)	1.609347	kilometres
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.4536	kilograms

SITE CHARACTERIZATION FOR THE MBCE/DIRT II BATTLEFIELD ENVIRONMENT TESTS

PART I: INTRODUCTION

Background

1. Efforts of the U. S. Army to evaluate correctly the performance of the Target Acquisition Function of advanced weapons systems in realistic battle environments have focused on a series of field exercises during the past three years. In recent months, the emphasis has been on dust and other material of local (terrain) origin generated by combat activity and carried in the atmosphere. Field exercises addressing this issue have been conducted at Eglin Air Force Base, Fla. (Smoke Week II, November 1978),* Grafenwohr, West Germany (June and October 1978), and White Sands Missile Range (WSMR), N. Mex. (DIRT I, October 1978) (Miller 1979). The work described herein was performed in support of the DIRT II (Dusty Infrared Test II) conducted at WSMR in July 1979.

2. Earlier work of relevance to this general problem was conducted by the U. S. Army Engineer Waterways Experiment Station (WES) in the 1950's and 1960's and resulted in the development of cratering models that allow one to predict crater dimensions from explosive size and placement for given soil conditions (Rooke 1961). These early models have been incorporated into some of the electro-optical (E-O) environmental forecast models to provide a rough estimate of the volume of material ejected into the atmosphere. However, since the emphasis of that earlier work was on ground effects rather than on the atmosphere, no data were obtained regarding the amounts of material from the craters that were actually suspended. Recent attention to this problem has

---

* U. S. Army Engineer Waterways Experiment Station. 1979. "Site Characterization for Smoke Week II, DRCPM-SMK-T," Letter report to PMO SMK, Mr. G. Bowman, U. S. Army Aberdeen Proving Ground, Md.

demonstrated that the amount of suspended material is very dependent on environmental features such as vegetation, moisture content, and weather. It has been a major objective of these various recent tests to supply this missing information. To that end, WES has been asked for support in performing suitable site characterizations for application to the E-O models.

3. Because the terrain contribution to battlefield obscuration is an area of interest to several commands and one in which data are lacking, the Corps of Engineers initiated in FY 80 a program specifically aimed at measuring the effects of topography, vegetation, and such soil parameters as moisture content, grain size, density, etc., on the atmospheric loading produced by combat activity. The goal is to develop means through parametric analysis whereby the atmospheric loading potential (ALP) of a region or area may be judged on the basis of known or observable parameters. Although the work described herein is in direct support of DIRT II, it is also complementary to the WES effort.

Purpose and Scope

4. The purpose of this work was to provide terrain and site characterization for the Munitions Bare Charge Equivalence (MBCE)/DIRT II test series, and to describe a standardized procedure for measurement and observation of such tests for the purpose of evaluating the ALP and the resultant obscuration.

5. The scope of work included pretest sampling and measurement of soil parameters and general characterization of the site, further sampling and measurement at individual explosion craters, and measurements of the craters themselves. Results of these measurements and observations will be presented in the following sections.

Test Descriptions

6. The MBCE/DIRT II tests were a joint effort by the Structures Laboratory of WES and the Atmospheric Sciences Laboratory (ASL) of WSMR.

The WES Structures Laboratory portion was the MBCE test and was concerned with duplicating munitions effects by the use of bare explosives. The ASL portion was DIRT II. WES Environmental Laboratory participation consisted of direct site characterization support to ASL, which constitutes the subject of this report and stereo photographic coverage of the tests. The latter work is not reported here.

7. For the DIRT II phase a 105-mm and a 155-mm howitzer were stationed approximately 4 km to the west and each fired 15 high explosive (HE) rounds into the test area described below. All rounds were "quick fuzed" for surface bursts. The MBCE phase consisted of in-place detonations of 105-mm and 155-mm ammunition and M112 charge demolition block, composition 4 (COMP-4) explosives in various configurations near the surface.

8. Measurements by ASL included continual meteorological data, airborne particle sampling, laser backscatter, and video imagery during all events. The WES Structures Laboratory provided the pyrotechniques and monitored ground motion and shock effects. In addition, the Night Vision and Electro-Optics Laboratory of ASL measured infrared (IR) and millimetre-wave transmission, and the Naval Research Laboratory measured visible and IR transmission through the dust clouds. Overall test documentation was the responsibility of ASL.

Site Description

9. The MBCE/DIRT II test was conducted at the "Queen 15" site near the northern end of the WSMR, latitude 33°22'N, longitude 106°40'W. It is located in the basin to the east of the San Andres Mountains approximately 50 miles* northwest of Tularosa, N. Mex. (Figure 1). The general soil type is an alluvial deposit of silty clay with varying amounts of sand of which a major component is gypsum which originates in the hills to the west and in the extensive deposits around Lake Lucero

---

* A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

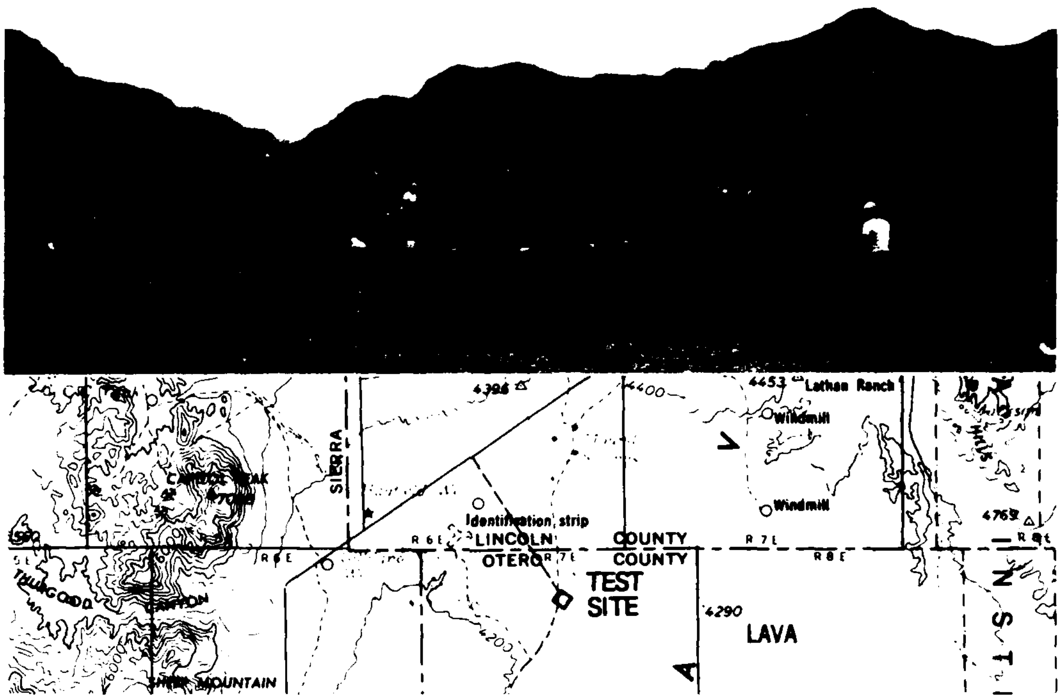


Figure 1. The DIRT II site is shown (top) viewed approximately southwest from the target area toward the *San Andres Mountains*. (Pole in the center marks the center of the area; location of the site is shown in the map.)

to the south. The San Andres Mountains are a limestone formation with exposed igneous intrusions resulting from north-south faulting with slight upthrusting of the western side and downthrust forming a graben on the east. This graben is known as the Tularosa Basin.

10. The main test area was a rectangle of 200 by 300 m that had been bladed and leveled. This target area lay in a shallow depression approximately 10 m below the elevation of the instrumentation sites at each end of the 2-km optical path on which it was centered. The surrounding terrain consisted of hummocks or dunes reaching 3 m in height and vegetated by coarse grass and brush of several varieties. In the target area itself, no evidence of vegetation remained because of the blading. For that reason, organic content was not analyzed.

11. The surface of the target area was lightly crusted by a desert pavement of 3- to 6-mm thickness and did not appear to have received

appreciable recent precipitation. (Precipitation and weather observations were taken at the site throughout the test period by the ASL and are reported by Kennedy (1980).) The soil beneath this crust was loosely consolidated to a depth of 10 to 20 cm. Deeper material was more firmly consolidated and displayed localized regions of high caliche content as revealed in some of the craters during testing. In a few craters, small pieces of crystalline gypsum were found.

12. The most notable feature of the soil in the MBCE/DIRT II test compared to previous tests of this kind was its high plasticity. Craters were typically lined with clotted material ranging up to 10 cm in size with finer material deposited on the rim and beyond. By contrast, craters at SMOKE WEEK II,* where the soil had a much higher sand content and no clay, were walled predominantly by loose granular material, and crater floors consisted of fine loose powder of several centimetres' depth. The difference is attributed to the clay content and higher moisture content.

* U. S. Army Engineer Waterways Experiment Station, op. cit.

PART II: PRESENTATION OF MEASUREMENTS

Site Characterization Procedures

13. A Standard Site Characterization Procedure has been proposed by WES to facilitate comparisons of results and conditions from different test sites. It is designed to provide results that will serve as direct input to models developed at WES and elsewhere to describe battlefield obscuration. This procedure is documented in Appendix A. Portions of the procedure relevant to the site characterization for the tests reported herein are discussed in more detail in the following paragraphs.

Description of Measurements and Procedures

14. The lack of data relating to obscurant-producing properties of soil under the influence of explosive cratering has complicated the selection of appropriate site characterization procedures. Of those methods currently used for soil measurement and analysis, the following have been chosen as providing a good compromise between ease of data collection and the provision of a reasonable set of soil properties potentially bearing on this problem (Black 1965). However, it is anticipated that some changes in the parameter set will likely be necessary as a better understanding of the atmospheric loading phenomena is obtained.

a. Cone index (CI). This test of soil strength is made by forcing a standard metal cone into the soil to a depth of 45 cm at a constant rate of penetration. The force required for penetration is indicated by the displacement of a micrometre gage and is read at 5-cm intervals. CI measurements were made throughout the test area at 50-m intervals and at selected craters as time permitted.

b. Moisture content (MC). This test is determined by recording the weight of a soil sample, drying the sample in an oven, and again weighing it to produce the ratio:

$$\frac{(\text{wet weight} - \text{dry weight})}{\text{dry weight}}$$

By using a metal cylinder of standard size to obtain this soil sample, the volume may also be known; thus, the density (wet and dry) can be determined. MC and density measurements were obtained for representative locations prior to testing and at selected craters during testing as time permitted.

c. Placticity index. This test is the difference between the liquid limit and the plastic limit for a soil material. Those limits are the moisture contents at which the soils display liquid and plastic properties, respectively, as determined by specified tests. Since those tests are conducted in the laboratory, these properties are determined after-the-fact using bulk samples collected from the test site.

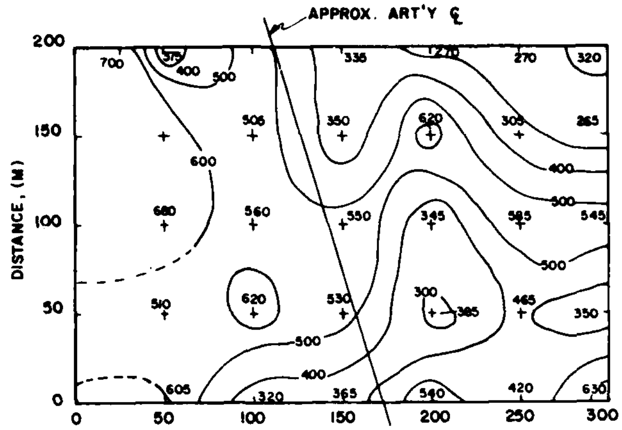
d. Size gradation. This test of the soil particles is determined by successive sieving using sieves down to mesh No. 200 (0.074 mm). Smaller sizes are analyzed in a hydrometer down to approximately 5-μm diameters.

e. Crater dimensions. This information is obtained by measuring apparent depth and diameter, that is, the dimensions of the visible boundaries of the fallback material rather than the true crater boundary. The value of crater dimensions in estimating obscurant production has not been established, but the use of crater models to estimate volume of ejected material requires these data.

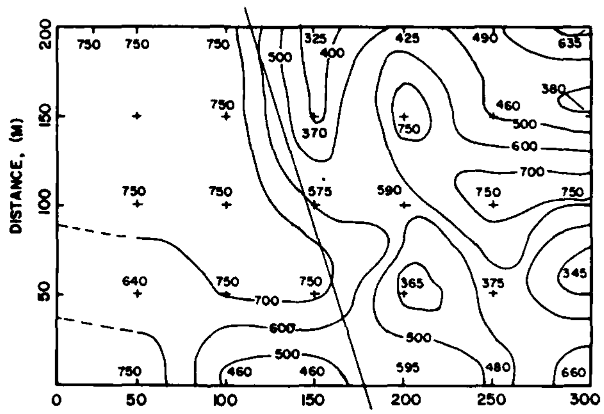
The conduct of these measurements occurred in three phases, designated as pretest, active phase, and posttest.

15. A site survey was made before the test series was initiated. This consisted of a walk-over inspection, collection of bulk soil sample, and systematic measurements of CI. A 50-m sampling grid was established over the site by placing stakes at 50-m intervals along the north-south center line and around the periphery of the 200- by 300-m test area. The soil was judged to be homogeneous and free of stones throughout the test area. The water table was approximately 3 m below the surface as observed at a test well on the north end of the area. Analysis of the bulk samples taken during this phase is included with later ones and is summarized in Tables 1 and 2.

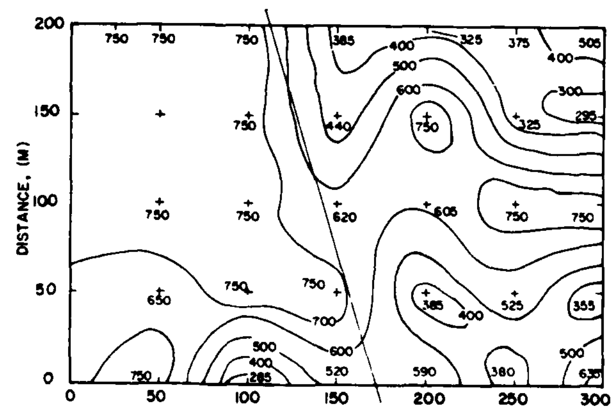
16. At each of the 50-m grid points a 1.27-cm (1/2-in.) cone penetrometer was used to obtain CI measurements to a depth of 45 cm (17.7 in.). From these data, averaged values were obtained for each of three layers (0-15, 15-30, and 30-45 cm) over the test area, and the contour maps of Figure 2 were produced. In the maps, it is evident that a generally



a. 0-15 cm depth



b. At depth 15-30 cm



c. At depth 30-45 cm

Figure 2. Contour maps of cone index data at the DIRT II test site showing cone index results for three levels over the 200 × 300 metre target area

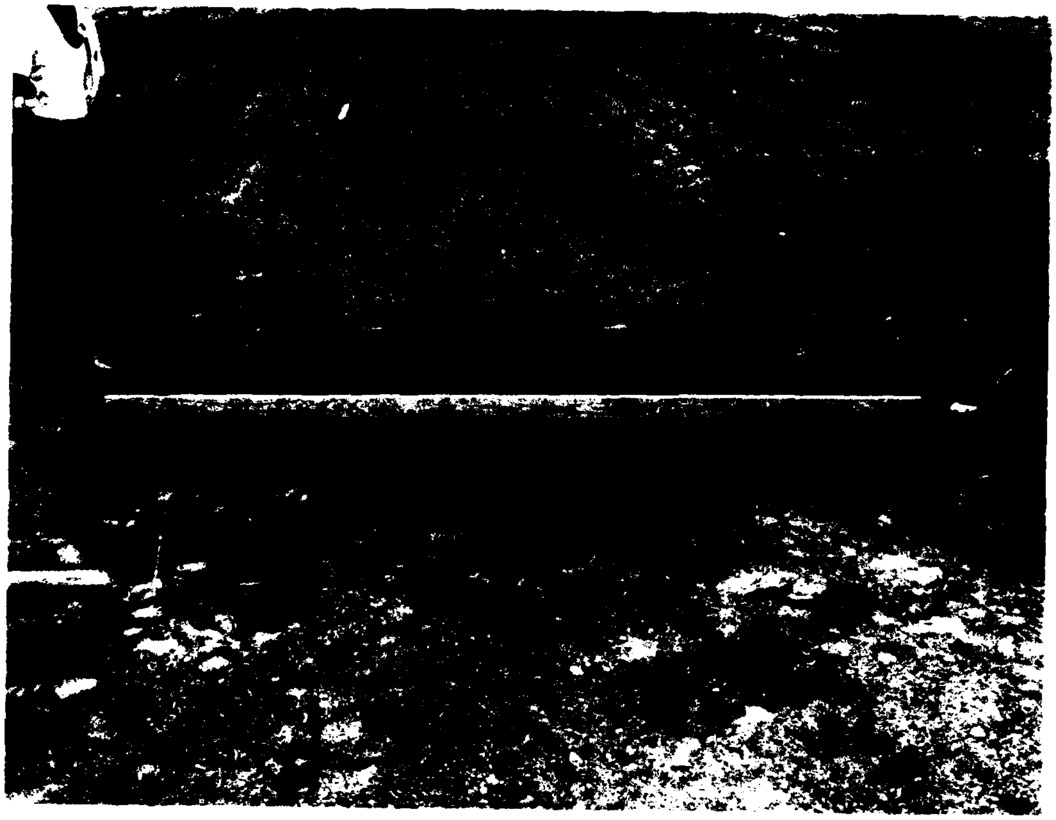
similar structure was detected at all three levels. A region of minimum CI values around 300 psi is prominent near the northern edge of the southwest quarter; that is the site of an earlier large crater test. At the north and south ends of the area along the center line maximum values reaching over 600 are observed. From the locations of the craters shown it is seen that most occurred in relatively harder soil. The CI is seen to be generally larger in the subsurface layers.

17. The sampling and measurements made during the test period were confined to the craters themselves and consisted of CI at crater rims and floors, MC/density at rims and beneath the walls at floor level (selected craters), bulk samples from some of the MC/density sites and crater profiles.

18. Crater profiles were taken along two diameters at right angles. For the artillery-fired munitions these were oriented along and normal to the line-of-fire. For static rounds, they were oriented north-south and east-west. From the profiles, values of depth and diameter were derived for each crater. The results of these measurements are summarized in Tables 3 and 4.

19. A distinct asymmetry was found in the craters produced by tube-delivered munitions. Because of this, some judgment is required in establishing the dimensions to be used. The practice has been to use the apparent diameter which is measured at the level of the original surface (Figure 3). However, most of these craters were characterized by shallow "wings" or troughs at right angles to the line-of-fire, and often by a similar but narrower trough in the downrange direction (Figure 4), making decisive measurements difficult. The method used was to estimate visually from plotted profiles a parabolic extension of the main crater to the original surface line and take the distance between points of intersection as the apparent diameter. These values are presented in Table 3.

20. Mean profiles were calculated for the 155-mm and 105-mm artillery produced craters and are shown in Figure 5. Mean profiles for the craters produced by static detonations are shown in Figures 6-11 where the grouping is according to type of munition and placement above



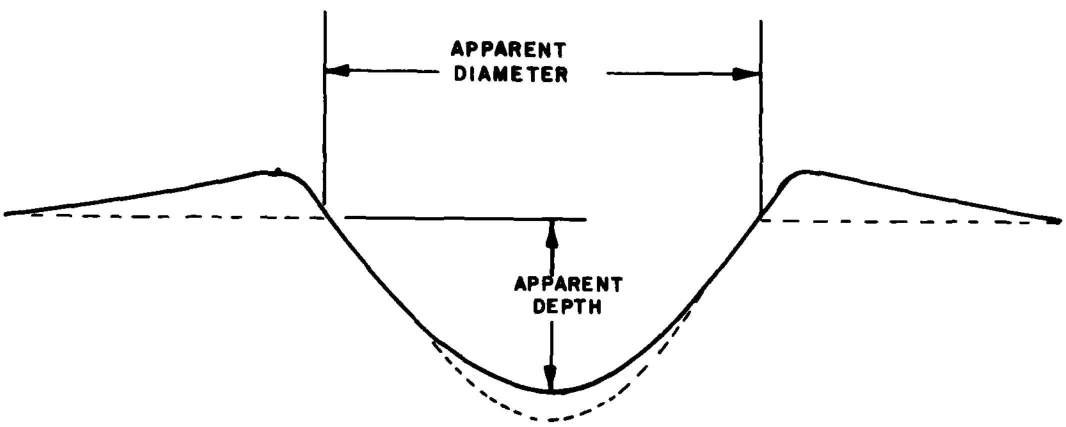
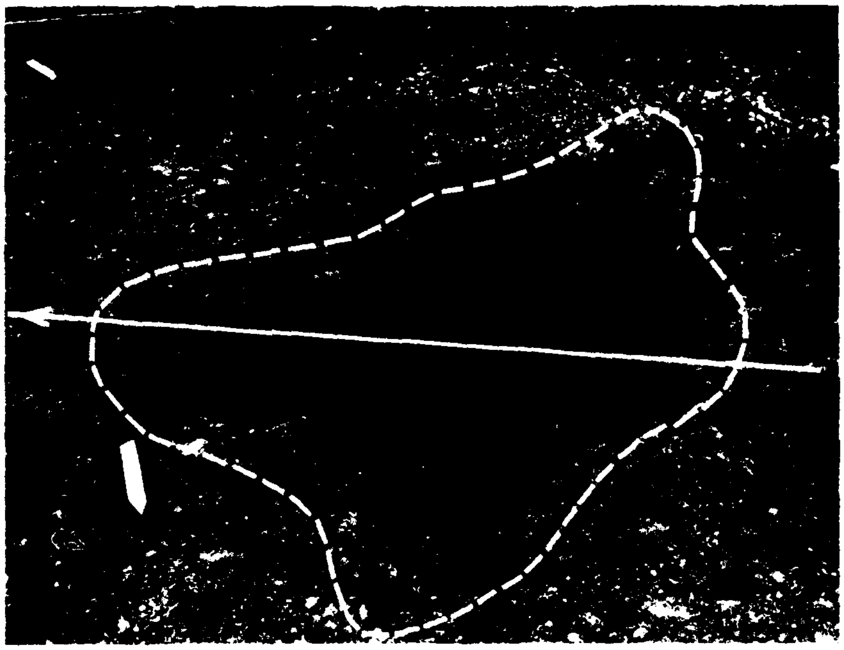
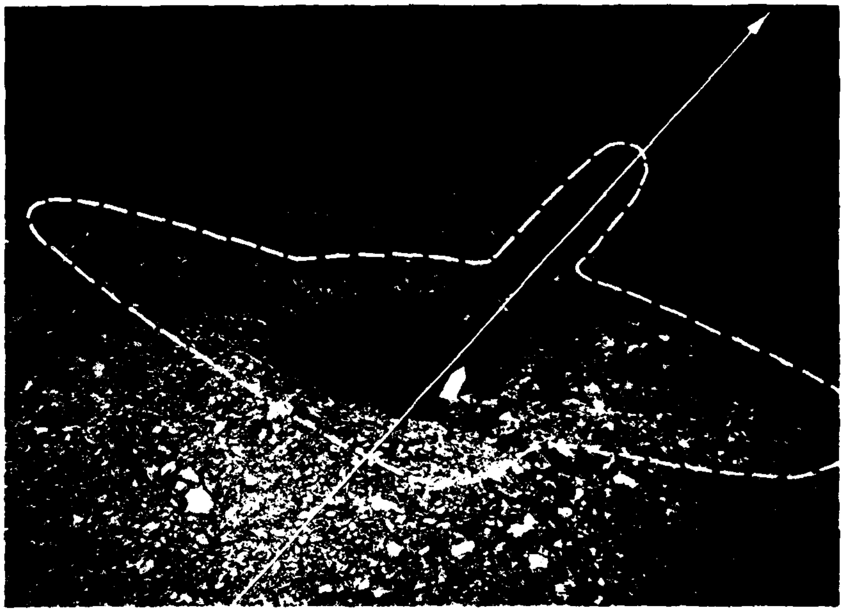


Figure 3. Photograph of crater, illustrating method of measurement, and drawing illustrating terms used in this report

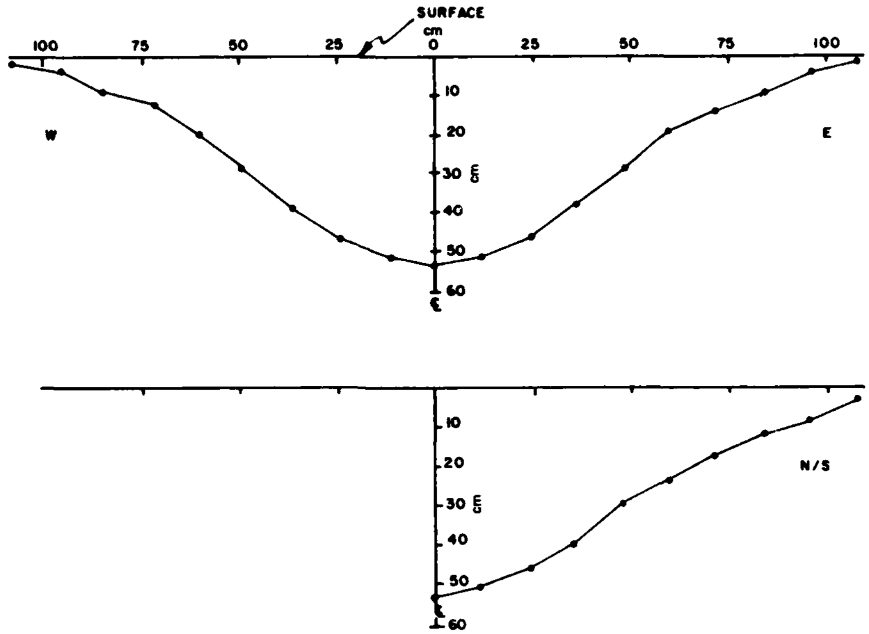


a. 155-mm artillery-produced crater

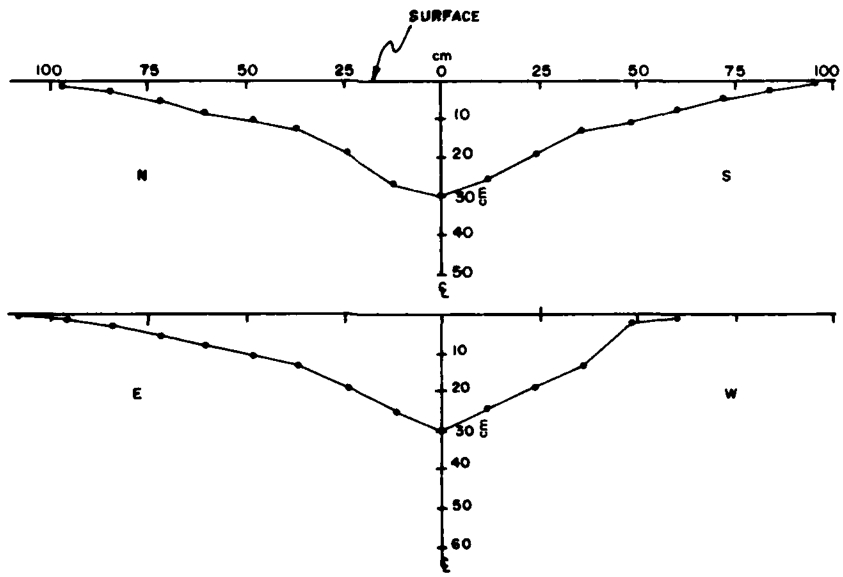


b. 105-mm artillery-produced crater

Figure 4. Photographs illustrating the asymmetric nature of 155-mm and 105-mm artillery-produced craters (Arrow indicates down-range direction.)



a. 155-mm artillery-produced crater



b. 105-mm artillery-produced crater

Figure 5. Mean profiles of 155-mm and 105-mm artillery-produced craters in the DIRT II test

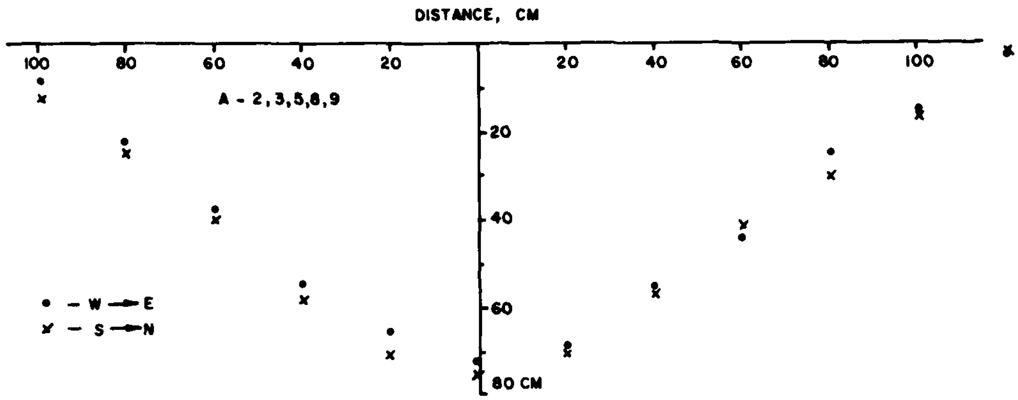


Figure 6. Mean crater profiles for 155-mm projectiles statically detonated in surface tangent buried configurations

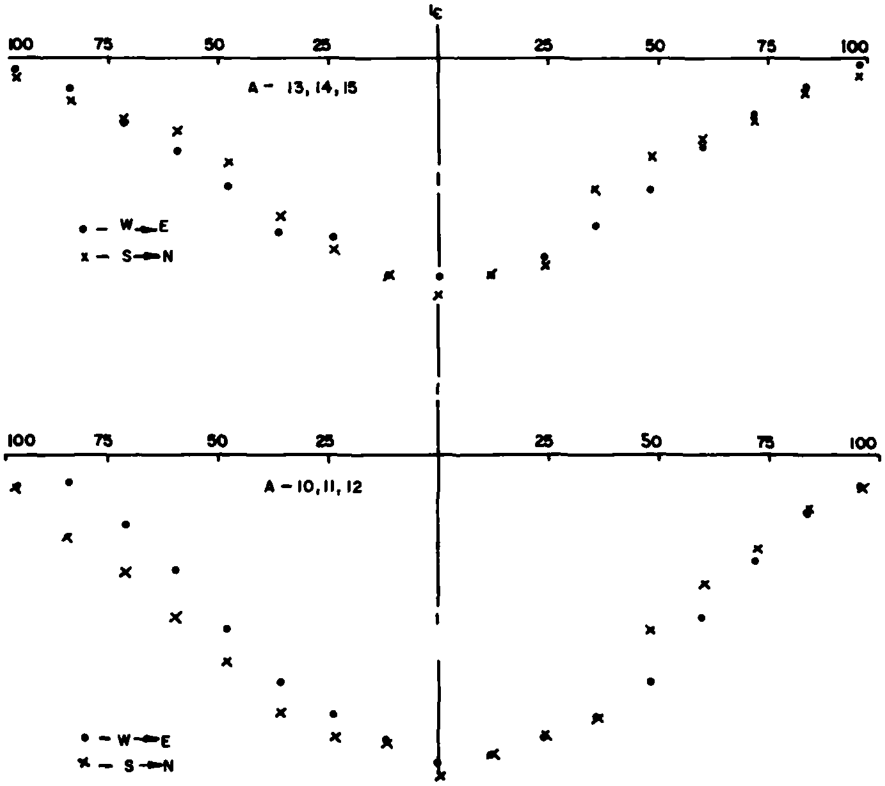


Figure 7. Mean crater profiles for 155-mm projectiles statically detonated in surface tangent configurations at angles of attack of 30° (upper) and 11.5° (lower)

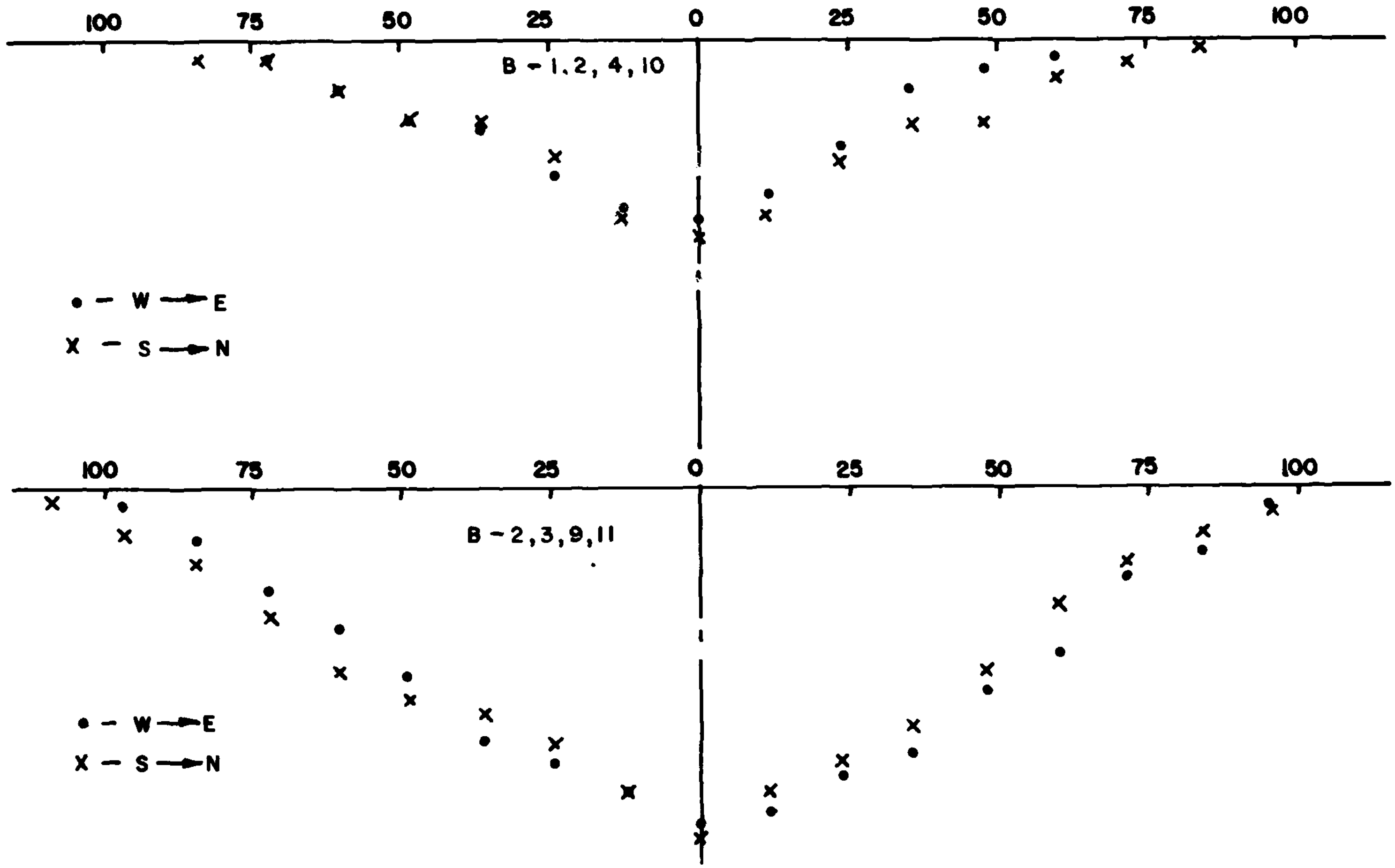
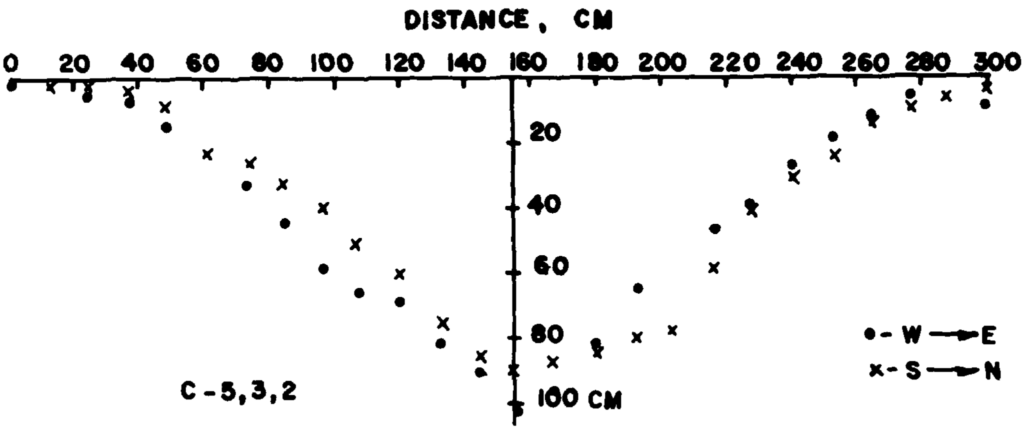
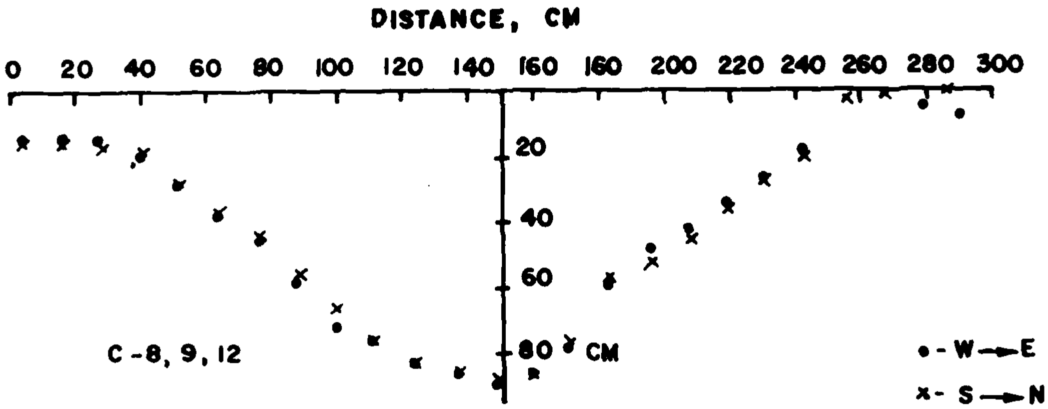


Figure 8. Mean crater profiles for 105-mm projectiles statically detonated in surface tangent (upper) and surface tangent buried (lower) configurations

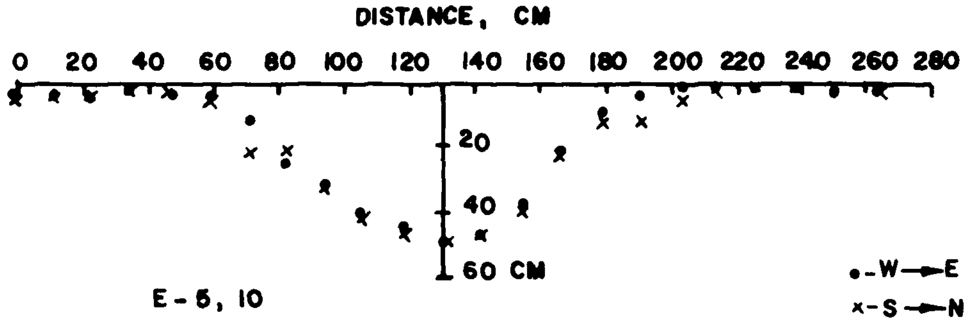


a. 80-deg angle of attack

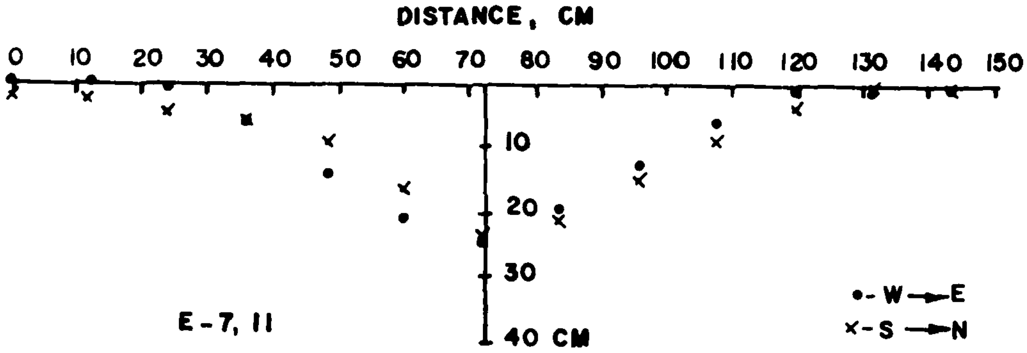


b. 60-deg angle of attack

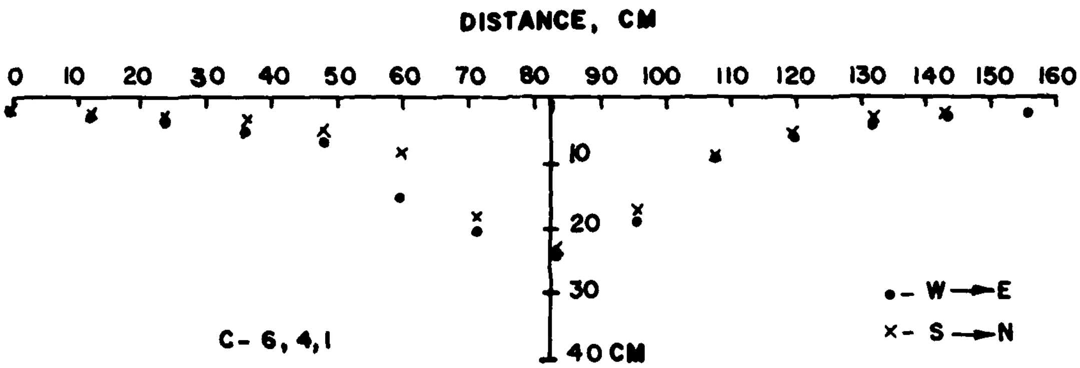
Figure 9. Mean profiles of craters produced by 4.2 mortar projectiles statically detonated in surface tangent buried configurations at 80-deg angle of attack and 60-deg



a. COMP-4, shots E-5 and E-10

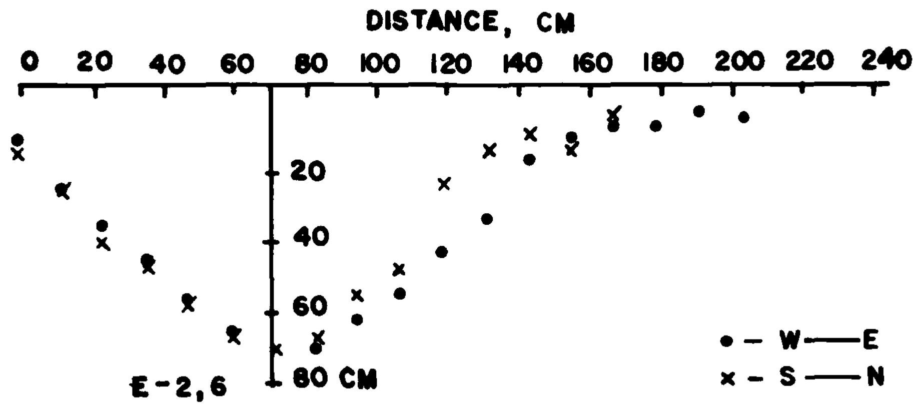


b. COMP-4, shots E-7 and E-11

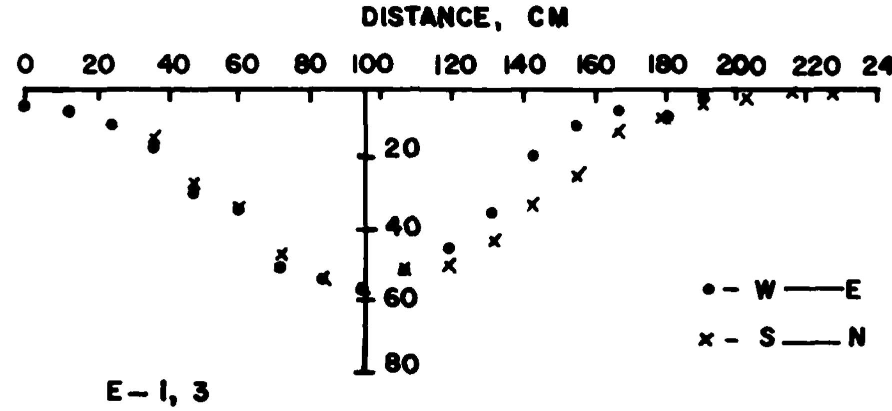


c. Surface tangent

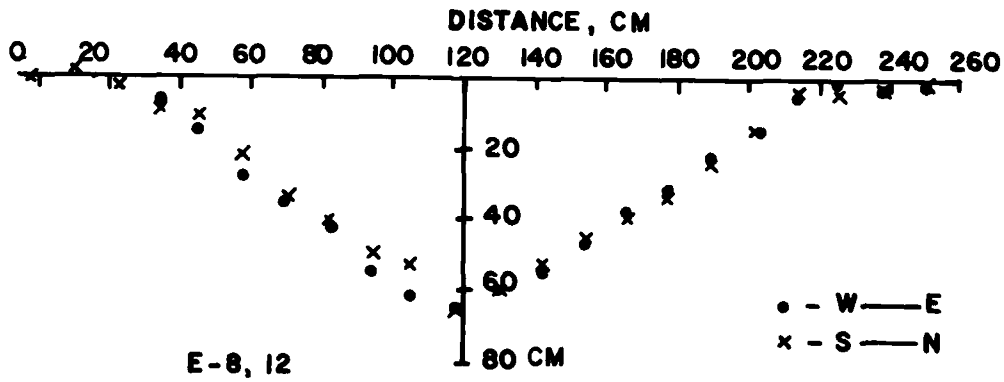
Figure 10. Mean profiles of craters produced by COMP-4 4.2 mortar (surface tangent)



a. Surface tangent buried (STB)



b. Surface tangent (ST)



c. Buried (B)

Figure 11. Mean profiles of craters produced by COMP-4 in surface tangent buried, surface tangent, and buried configurations

or below the surface. These groupings coincide with the arrangement of Table 4.

21. The bulk samples were tested in the laboratory to produce grain-size distributions in the form of percentage fine curves (Figures 12 and 13), and to establish the liquid and plastic properties of the DIRT II soil (Table 1). The classification of this soil on the basis of its texture or size gradation is shown in Figure 14 where it is seen to be a loamy sand (U. S. Department of Agriculture Soil Survey Staff 1951). The Unified Soil Classification System (USCS) classification of this soil is SM. Soils from other obscuration tests sites are also identified in the chart for reference purposes.

22. In the hydrometer analysis used to establish the percentage fines below 0.074-mm diameter, some of the samples were observed to flocculate (aggregate loosely) so that accurate data could not be obtained. In an effort to extend the curves for those samples (E-2, E-5, C-2, C-4), an electron microscope belonging to the Concrete Laboratory, WES Structures Laboratory was employed. The material passing a No. 200 sieve was collected on an adhesive strip and counted visually under 200X magnification. However, because of their slow settling value, it is believed that the smaller particles (<10 μm) were not adequately collected in these samples, so that no attempt has been made to extend their corresponding size gradation curves.

23. Figure 15 shows a sampling of the electron microscope results at higher magnification. The particles shown are typical of the DIRT II test site material and demonstrate their highly irregular shapes and cohesive tendency. The platey forms characteristic of clays are also evident.

24. In addition to the electron micrographs an x-ray diffraction analysis was made on this material, the results of which appear in Table 2. These samples were taken from bulk samples B-2, C-2, C-4, E-2, and E-5 at depths as shown in the table. Among nonclays, quartz and calcite were present in all samples. In lesser amounts, the clay minerals vermiculite and mica were found in all. Calcium sulfate in the form hemihydrate rather than gypsum is indicated. The solubility of hemihydrate in water is a probable cause of the difficulty in the hydrometer

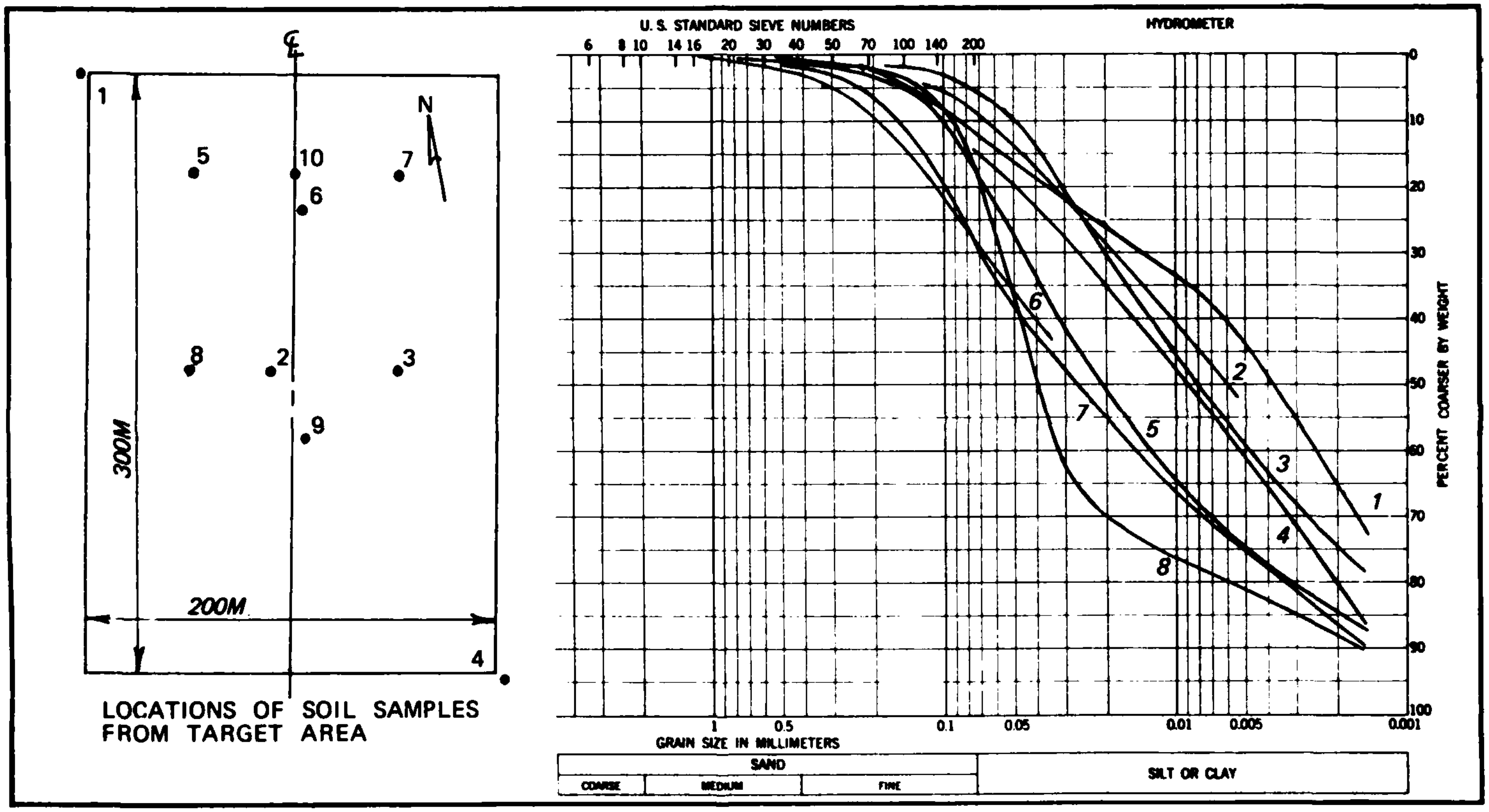


Figure 12. Particle size gradation of soils in surface samples from the DIRT II test site (Numbers correspond to the locations indicated in the inset diagram of the target area.)

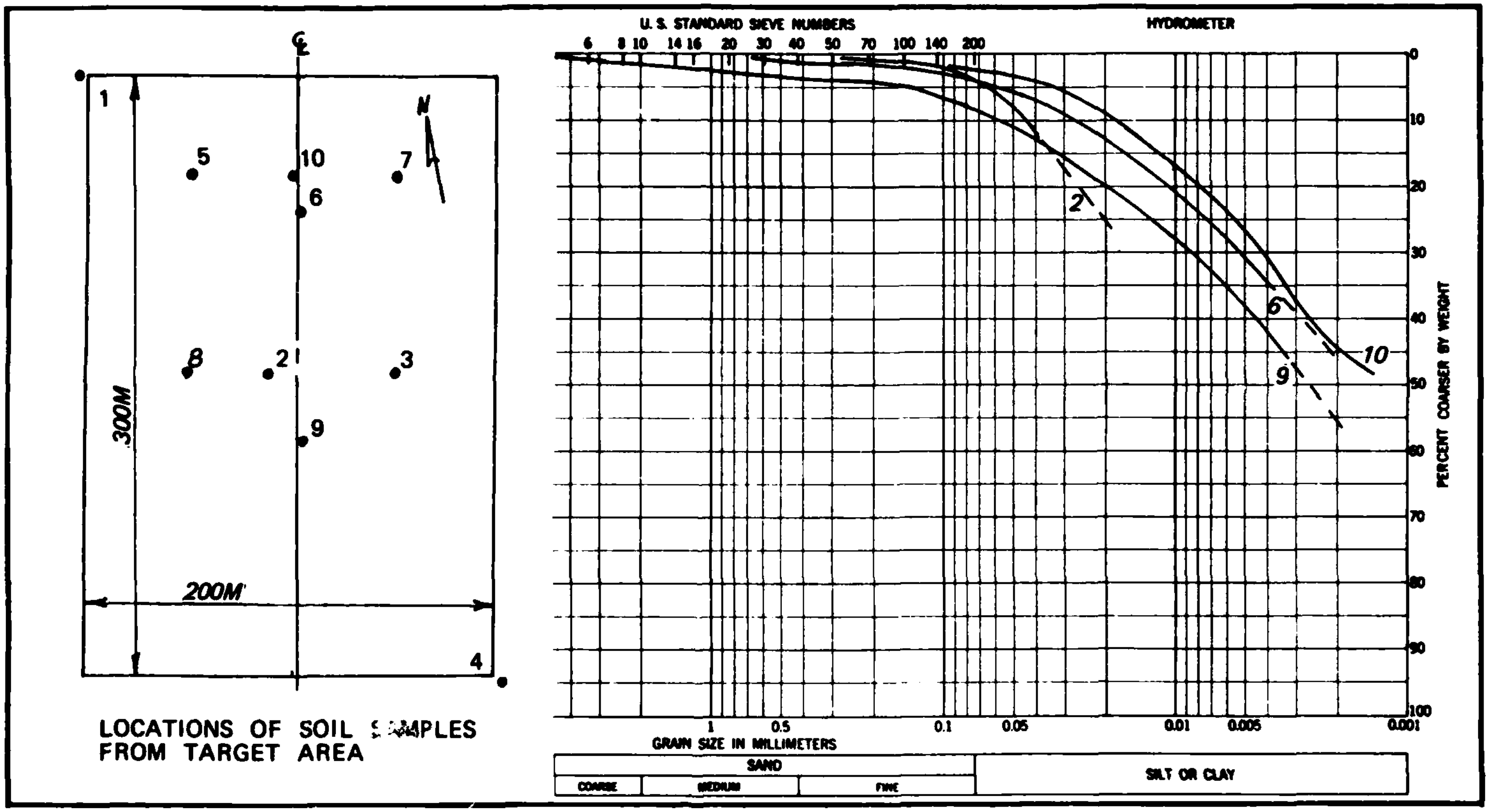


Figure 13. Particle size gradations of soils in samples from 50-60 cm (6), 70-80 cm (10), 80-90 cm (9), and 90-100 cm (2) below the surface in the target area (inset) at the DIRT II test site

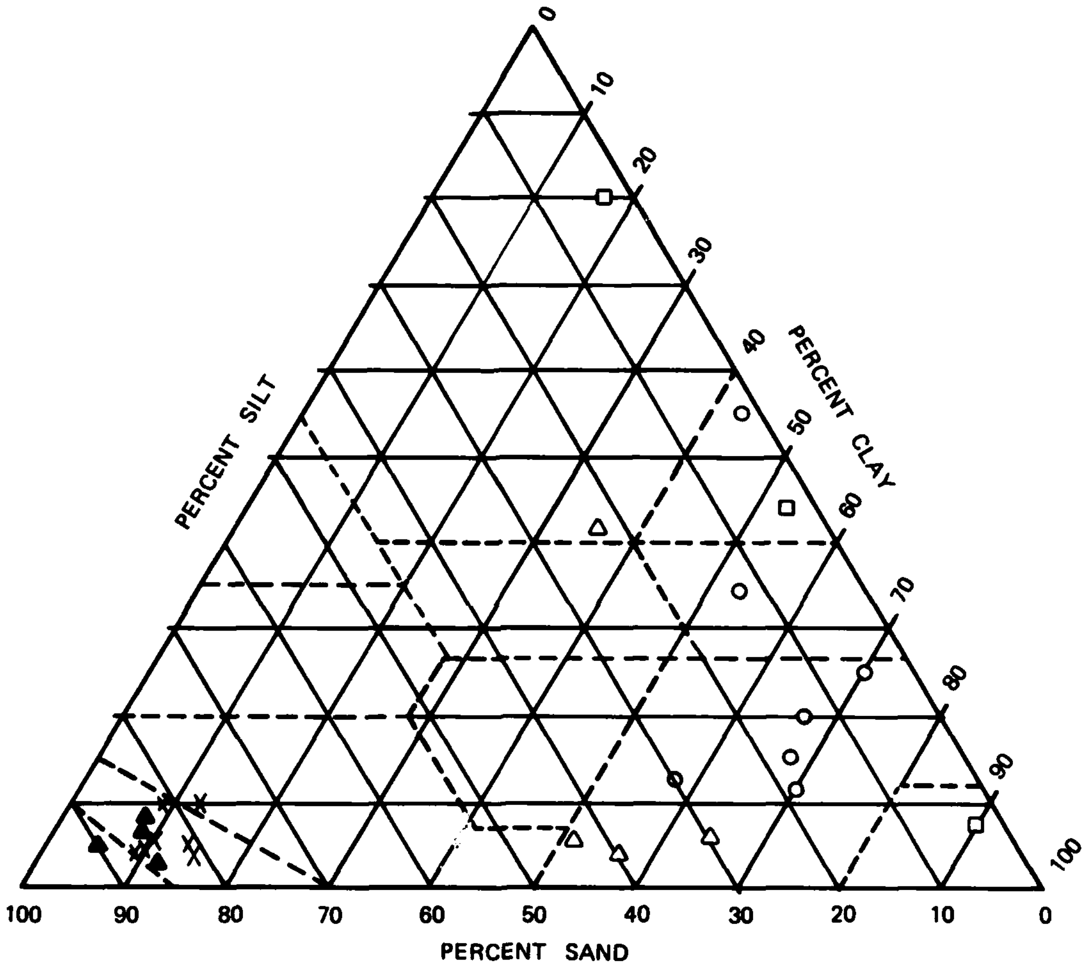


Figure 14. Soil classification chart showing the DIRT II soil (o), together with soils from Eglin Air Force Base (▲), DIRT I (x), Redstone Arsenal (Δ), and WES (□)

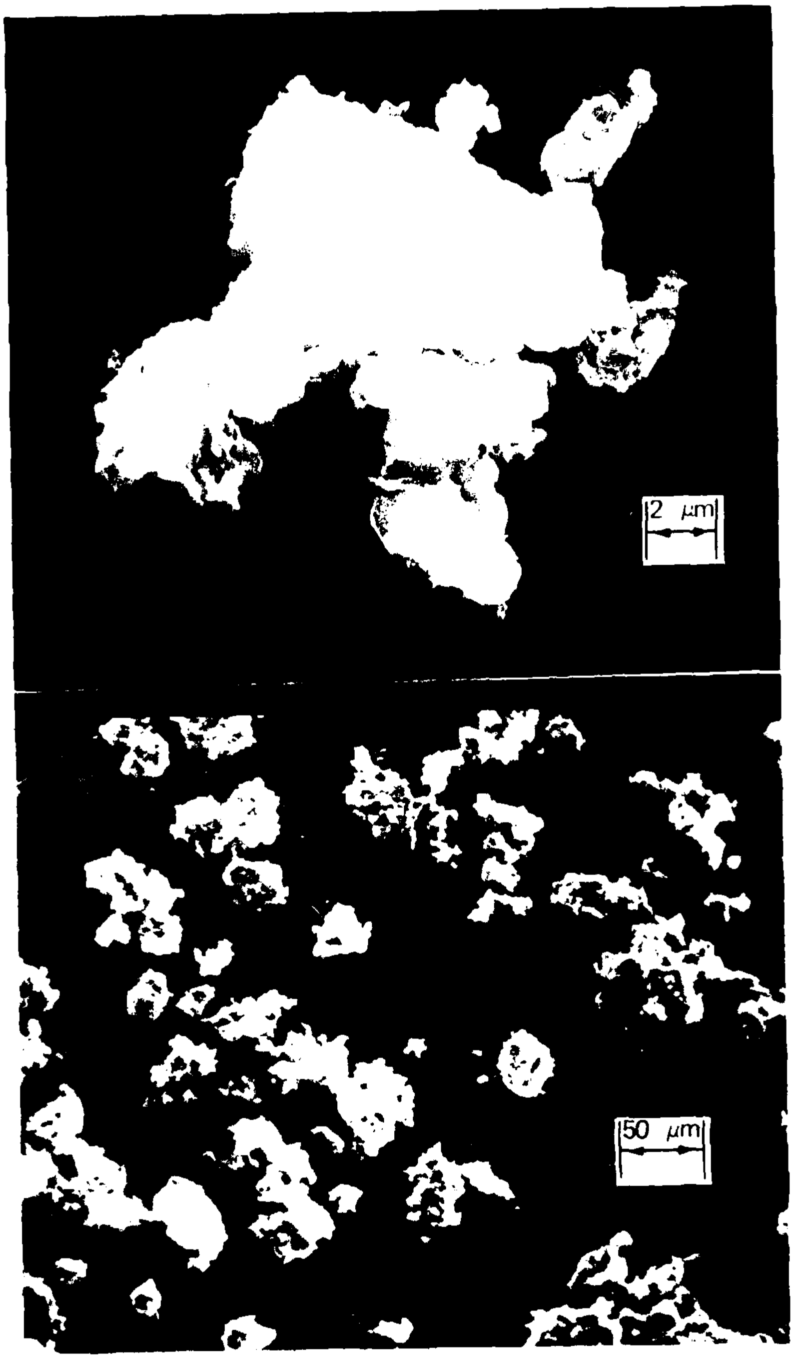


Figure 15. Electron micrographs of typical soil particles from the target area, DIRT II site

analysis of these samples, and thus, the other material might be expected to contain gypsum.

Analysis and Results

25. Assuming that the volume of the apparent crater is more representative of the amount of ejecta than the volume of the true crater, it is pertinent to examine the apparent crater volumes for the different munitions used in the tests. The mean values for apparent crater volumes for the 105-mm and 155-mm munitions were 0.16 m^3 and 0.67 m^3, respectively. The ratio of these volumes is 4.2, which is only slightly greater than the ratio of the yields for the two munitions (2.93).

26. From the gradation data for the site the mean percentage of fines less than 10.0 μm is found to be 58.1 percent; thus, using the above figures the mean volumes of fines of sizes less than 10.0 μm diameter are 0.093 m^3 for 105-mm and 0.392 m^3 for 155-mm rounds. With a mean dry density of 2.72 g/cm^3 this yields 254 and 1070 kg of material, respectively, of sizes less than 10-μm diameter from the two munitions. When distributed over a spherical volume 20 m in diameter, these amounts yield loading densities of 0.061 and 0.255 kg/m^3, or mass loading ratios (mass of solid plus air divided by the mass of air) of about 0.03 and 0.13, respectively. (For purposes of comparison, Pinnick (Kennedy 1980) obtained maximum values of the order of 1 g/m^3 at ground level using a particle counting instrument.)

27. Although it is not assumed that Pinnick's figures are representative of the cloud, it is clear that the figures based on apparent crater volume represent more mass than remains in the cloud. Cohesive forces will bind many fine particles into larger clumps so that they will fall out rapidly. The walls and floor of the crater and the surrounding surface contain substantial amounts of material that has fallen back. Furthermore, part of the crater volume is due to compaction of the medium. In an effort to assess the amount of fallback, one 105-mm crater (T27) was carefully scooped clear of debris. This was done by removing the loose material from the walls to a depth at which an

interface of firmly consolidated soil was reached. This interface was taken to be the true crater boundary. The material was scraped to the bottom of the crater and removed until one-half of the crater was cleared. (It was necessary to stand in the other half.) The profiles obtained appear in Figure 16. The resulting volume was found to be 0.41 m^3. Thus, the volume of fallback material for this 105-mm crater is 0.25 m^3. If it is assumed for the sake of argument that compaction contributes 30 percent of the volume (reasonable for clay), the true volume of ejecta is 70 percent of 0.41 m^3, or 0.29 m^3. Subtracting the 0.25 m^3 of fallback leaves 0.04 m^3 of material actually removed. Computing fines as above leads to 0.023 m^3 or about one-quarter of the previous figure.

28. It is likely that this estimate is still excessive, but it represents the limit to which the available data can be applied. Measurements of fallout around the crater could improve these results, but it must be remembered that this kind of accounting method, searching for residues among variables that are orders of magnitude larger, is a risky one. The relative variation in volume for various munitions may be the best that can be hoped for without actual measurements in the cloud.

29. Figure 17 compares the crater sizes of the various events by showing the natural log of the quantity depth times diameter squared (dD^2) versus the natural log of equivalent trinitrotoluene (TNT) weight (pounds). Linear least squares fits have been obtained for the COMP-4 data for the surface tangent (ST) and buried tangent (STB) configurations. As shown, the craters produced by the corresponding artillery configurations lie to the right of these two lines, with slightly different slopes. The data show that buried configurations produce larger craters. Two C-4 events were placed at depths greater than the STB positions and are combined to yield the isolated point to the right of the lower C-4 curve. The data from which the figure was produced are those of Table 4. Table 5 shows the data collected for craters produced by static detonations of the explosives.

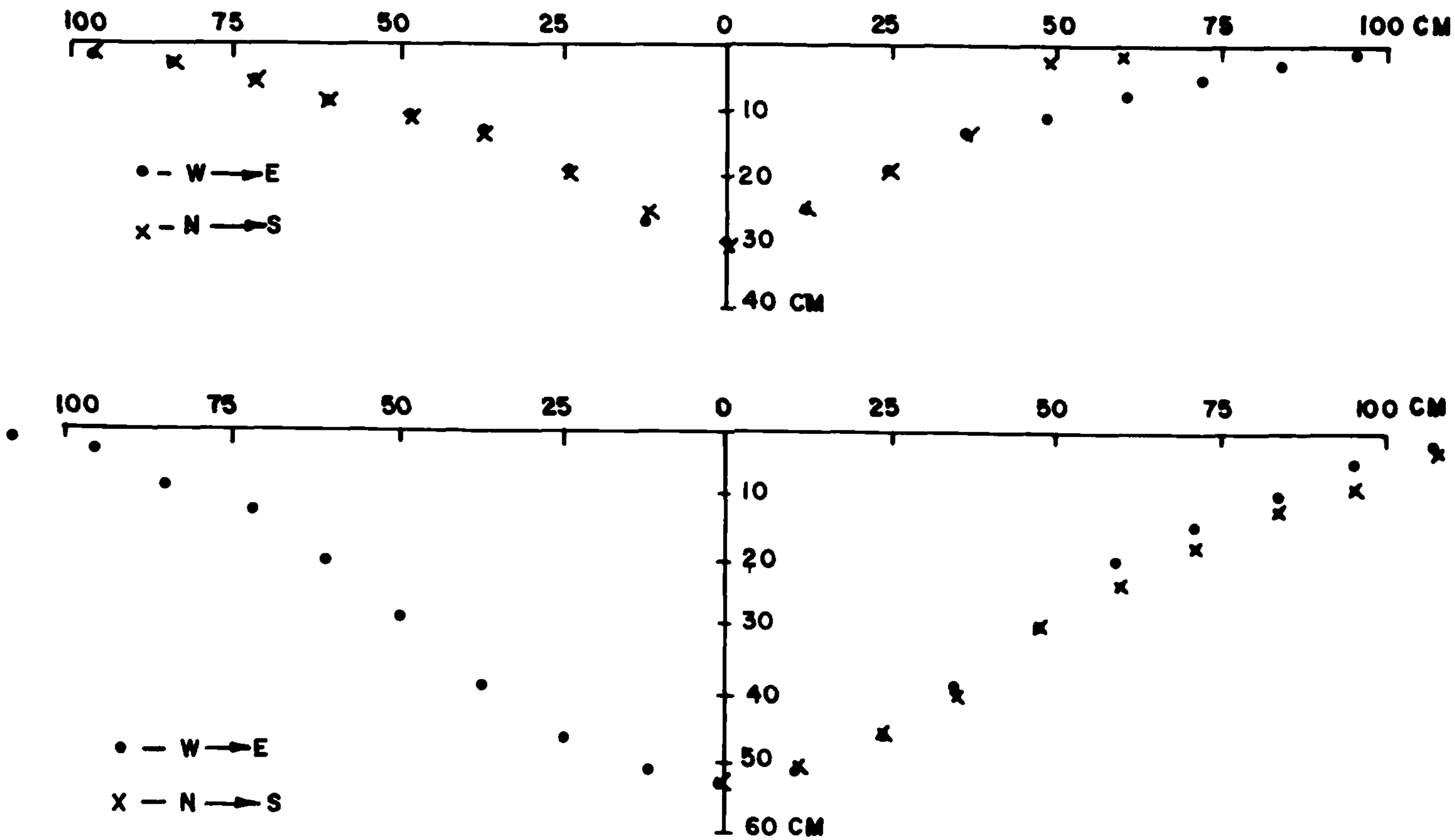


Figure 16. Profiles for 105-mm artillery crater No. 27 apparent boundary (upper) and true boundary after removal of debris (lower)

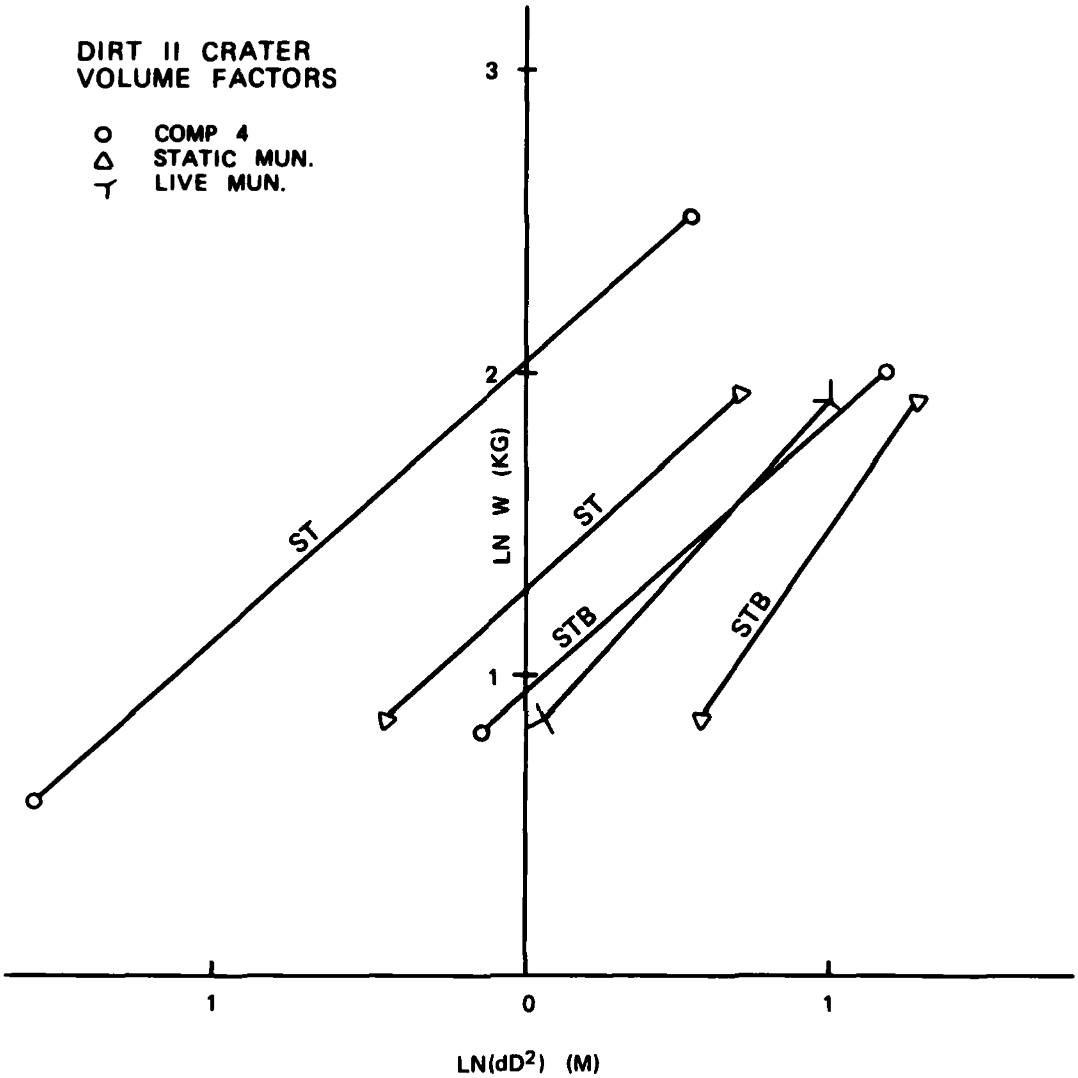


Figure 17. Comparison of the crater volume factor (dD^2) versus equivalent trinitrotoluene (TNT) weight for craters produced by cased munitions and COMP-4 in surface tangent (ST) and surface tangent buried (STB) configurations

PART III: CONCLUSIONS AND RECOMMENDATIONS

Conclusions

30. The soil at the MBCE/DIRT II site is classified as a brownish clay of medium plasticity. Organic content was judged nil. Moisture contents were moderate (for clay) ranging between 15 and 20 percent generally. Size gradations show percentage fines to be moderate also, ranging from 25 percent to 65 percent for surface samples, but somewhat higher for samples in the 40-cm to 80-cm layers. The average specific gravity of the soil is 2.73. Predominant clay minerals are illite and vermiculite, and predominant nonclays are calcite and quartz.

31. Explosive cratering results yielded consistent sizes and shapes for artillery delivered 105- and 155-mm rounds. More varied results occurred with statically placed munitions, probably due to varied orientations. Positive correlations of crater size with depth of burial and with munition size are clear. However, no significant correlations of crater size to observed cone indexes or moisture contents were evident in the data collected.

Recommendations

32. It is recommended on the basis of these results that future tests include thorough pretest site surveys of cone index and moisture content to allow charge placements to take advantage of extremes that may occur. It is further suggested that the measurement of crater dimensions are not an adequate method for judging dust production. Preliminary surveys of dust cloud photography (not described here) are as yet inconclusive in this regard, but may aid in determining the value of crater measurements. However, variations in such soil properties as plasticity are known to lead to variations in crater size that may be independent of dust cloud properties.

33. Questions regarding crater size notwithstanding, it is clear that some improved method for determining or sampling the material lofted

into the air by explosives is needed. There is as yet no well-defined relationship between dust cloud density and soil characteristics, and there is no fully satisfactory method for measuring the lofted material. Recommendations at this point favor the use of sampling pans or pads and adhesive impactor devices placed near the surface at varying distances from the detonation site. Testing of such methods is expected to be undertaken in the future at WES.

REFERENCES

Alpha Lux Company. 1970. "The Speedy Moisture Tester," Bulletin AL-39, New York.

Black, C. A. et al., eds. 1965. Methods of Soil Analysis, Part I, American Society of Agronomy, Madison, Wis.

Kennedy, B. W., ed. 1980. Dusty Infrared Test II (DIRT II) Program, Chapter 8, U. S. Army Electronics Research and Development Command Report No. 05D1366, White Sands Missile Range, N. Mex.

Miller, C. A. 1979. "Terrain Characteristics at DIRT I Test Site, WSMR New Mexico," Miscellaneous Paper EL-79-1, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

Rooke, A. D. 1961. "Cratering from High Explosive Charges; Analysis of Crater Data," Technical Report 2-547, Report 2, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

U. S. Army Engineer Waterways Experiment Station. 1962. "Tropical Soil Studies in Panama and Puerto Rico, Plan of Tests," Vicksburg, Miss.

__________. 1968. "Environmental Data Collection Methods, Vol IV: Vegetation," Instruction Report No. 10, Vicksburg, Miss.

U. S. Department of Agriculture Soil Survey Staff. 1951. Soil Survey Handbook No. 18, U. S. Department of Agriculture Manual, U. S. Government Printing Office, Washington, D. C.

Weaver, J. E., and Clements, F. E. 1938. Plant Ecology, McGraw-Hill, New York, pp 10-31.

Table 1

Summary of Soil Analysis for Bulk Samples*

Bulk Sample No.	Sample Location		Atterberg Limits			Soil Type (USCS)**	Soil Classification (USDA)†	Specific Gravity	Grain Size % Finer by Weight 0.074 mm	Depth cm
	X	Y	LL	PL	PI					
B-2	91.0	100.2	21	15	6	CL-ML	Silt loam	2.71	71.6	Surface
B-6	116.3	90.6	29	19	10	CL	Silt loam	2.67	95.2	Surface
C-2	50.0	100.0	33	18	15	CL	Silt	2.77	95.7	Surface
C-2	50.0	100.0	46	20	26	CL	Silty clay	2.74	98.3	70-80
C-4	184.4	89.3	30	16	14	CL	Silty clay	2.73	92.0	80-90
BS-7	50.0	150.0	27	20	7	CL	Silt loam	2.67	84.7	Surface
BS-12	150.0	150.0	23	20	3	ML	Silt loam	2.70	82.7	Surface
E-2	150.0	100.0	33	18	15	CL	Silty clay loam	2.72	92.3	Surface
E-2	150.0	100.0	39	18	21	CL	Silt	2.76	96.8	90-100
E-5	75.0	98.7	22	15	7	CL	Silt	2.69	72.4	Surface
E-5	75.0	98.7	43	20	23	CL	Silty clay	2.80	96.1	50-60
BS-1	0.0	210.0	30	16	14	CL	Silty clay loam	2.72	88.2	Surface
BS-4	305.0	-5.0	27	17	10	CL	Silt loam	2.72	86.9	Surface

* Bulk samples before impact test.
** Unified Soils Classification System.
† U. S. Department of Agriculture.

Table 2

Mineral Composition of Selected Samples from the DIRT II Test Site

Material	Sample No. →	1	2	3	4	5	8
	Crater Location →	E-5	C-2	E-2	E-2	B-2	C-4
	Depth, cm →	50-60	Surface	Surface	90-100	Surface	90-100
Clays							
Smectite		--	--	Minor	--	--	--
Chlorite		--	Rare	Minor	Rare	Rare	Rare
Vermiculite		Minor	Minor	--	Minor	Minor	--
Illites (mica)		Common	Minor	Minor	Minor	Minor	Minor
Kaolinites		Common					
Nonclays							
Hemihydrate		Common	Rare	Rare	Common	Rare	--
Quartz		Common	Common	Common	Common	Common	Common
Potassium		--	Minor	Rare	Minor	Minor	Minor
Plagioclase		Minor	Rare	Rare	Minor	Common	Minor
Calcite		Common	Common	Common	Common	Common	Intermed
Dolomite		Rare	Rare	Rare	Rare	Rare	Rare
Hematite		Rare	Rare	--	Rare	--	Rare

Note: Intepretation: Rare <5%; minor, 5-10%; common, 10-25%; intermediate, 25-50%; abundant <50%.

Table 3

A Summary of Crater Measurements for Static Detonations in the DIRT II Test

Event Designation	Placement*	Angle of Attack deg	Crater Dimensions, m Diameter	Crater Dimensions, m Depth
155-mm				
A-13, A-14, A-15	ST	30	1.92	0.52
A-10, A-11, A-12	ST	11.5	1.99	0.72
A-1, A-4	ST	20	1.90	0.42
A-2, A-5, A-8, A-9, A-3	STB	All	2.26	0.73
105-mm				
B-1, B-4, B-10, B-12, B-6, B-7	ST	All	1.43	0.31
B-8, B-5, B-11, B-9, B-2, B-3	STB	All	1.86	0.52
COMP-4 (27 lb)				
E-1, E-3	ST	--	1.85	0.50
COMP-4 (16 lb)				
E-2, E-6	STB	--	2.25	0.65
COMP-4 (8 lb)				
E-8, E-12	B	--	1.85	0.50
COMP-4 (5 lb)				
E-5, E-10	STB	--	1.40	0.45
COMP-4 (4 lb)				
E-7, E-11	ST	--	0.91	0.24
4.2 Mortar				
C-6, C-4, C-1	ST	80	0.80	0.25
C-5, C-3, C-2	STB	80	2.22	0.[illegible]2
C-8, C-9, C-12	STB	60	2.12	0.71

* ST = above and tangent to surface, STB = below and tangent, B = buried.

Table 4

Artillery Rounds Crater Data

Crater No.*	Munition Type	Crater Location X	Crater Location Y	Crater Dimension, m E-W	N-S	Depth	Cone Index Data at Depth, cm 15	30	45	Moisture Content Percent	Depth, m	Density g/cm^3 Wet	Dry
T1	155	154.6	100.5	1.8	2.7	0.60	345	400	365	--	--	--	--
T2	155	154.7	92.8	1.8	2.0	0.70	265	355	290	--	--	--	--
T3		155.7	127.8	--	--	--	440	480	310	12.8/20.9	10/65	--	--
T4	155	150.1	91.4	1.7	1.6	0.58	260	390	300	--	--	--	--
T5	155	149.6	85.5	1.4	1.3	0.50	550	750+	750+	--	--	--	--
T6	155	140.0	75.0	1.4	1.5	0.55	315	455	530	15.2/--	10/--	1.73	1.51
T7	155	137.0	73.6	1.3	1.6	0.45	590	750+	750+	--	--	--	--
T8	155	133.9	59.1	1.6	1.6	0.50	310	360	430	--	--	--	--
T9	105	129.9	81.3	1.1	1.4	0.30	395	595	675	--	--	--	--
T10	105	126.0	78.8	1.0	0.9	0.30	375	560	635	--	--	--	--
T11	105	126.3	80.3	1.0	0.8	0.25	445	550	650	--	--	--	--
T12	105	136.3	87.2	1.0	0.9	0.25	515	620	580	--	--	--	--
T13, 14	105	141.7	97.7	Double Crater, No Data									
T15	155	147.7	102.3	2.0	2.6	0.60	330	465	515	--	--	--	--
T18	105	143.2	109.2	1.3	1.1	0.65	400	365	350	--	--	--	--
T19	105	148.6	113.2	1.3	1.0	0.28	345	415	335	--	--	--	--
T20	105	149.1	117.0	1.0	1.2	0.30	500	645	625	--	--	--	--
T21	105	145.8	131.8	0.9	1.2	0.35	365	475	480	11.3/--	10/--	1.65	1.48
T22	105	151.6	137.8	0.8	0.9	0.35	--	--	--	--	--	--	--
T26	155	175.0	181.8	1.5	1.7	0.05	--	--	--	--	--	--	--
T27	105	174.1	163.9	1.0	1.0	0.35	--	--	--	--	--	--	--
T28	155	163.9	149.1	1.7	1.7	0.50	--	--	--	--	--	--	--
T29	105	160.0	136.3	1.1	1.2	0.25	--	--	--	--	--	--	--

Table 5

Static Detonations--Crater Data

Crater No.*	Placement Type	Crater Location X	Crater Location Y	Crater Dimension m E-W	N-S	Depth	Cone Index Data at Depth, cm 15	30	45	Moisture Content Percent	Depth, m	Density g/cm^3 Wet	Dry
A13	Surface	140.0	100.0	1.9	2.0	0.56	200	275	325	15.7/23.3	10/50	--	--
A10	Surface	130.0	100.0	1.9	2.0	0.65	170	130	150	16.2/--	10/--	--	--
A14	Surface	159.6	110.3	1.9	1.9	0.50	180	228	130	--/18.4	--/60	--	--
A15	Surface	160.0	90.0	1.8	2.0	0.50	260	380	410	--	--	--	--
A12	Surface	170.0	89.8	2.0	2.4	0.83	130	140	145	--	--	--	--
A11	Surface	170.0	110.2	2.0	2.0	0.70	250	235	200	--	--	--	--
A1	Surface	154.6	100.0	2.0	2.0	0.45	305	390	310	--	--	--	--
A7	Surface	110.0	85.0	2.0	2.2	0.55	280	235	180	--	--	--	--
A2	Buried	125.0	80.0	2.2	2.6	0.90	220	280	250	--	--	--	--
A5	Buried	115.0	90.0	2.3	2.2	0.75	155	210	255	10.0/27.3	10.0/100	1.45/202	1.32/1.59
A8	Buried	125.0	90.0	2.4	2.6	0.80	135	290	325	--	--	--	--
A9	Buried	120.0	90.0	2.1	2.2	0.60	235	335	315	--	--	--	--
A4	Surface	110.0	100.0	1.9	2.2	0.40	190	345	370	12.6/21.0	10.0/55	1.55/1.76	1.37/1.56
A3	Buried	120.0	100.0	2.3	2.5	0.70	--	--	--	--	--	--	--
B6	Surface	116.3	90.6	1.9	1.3	0.27	240	380	415	--	--	--	--
B7	Surface	116.2	80.6	1.7	1.6	0.33	240	385	385	--	--	--	--
B8	Buried	108.1	80.9	2.1	1.8	0.50	245	305	325	--	--	--	--
B5	Buried	108.0	90.6	1.9	2.0	0.51	285	295	380	--	--	--	--
E1	Surface 27 lb	116.5	99.8	1.9	1.6	0.52	260	360	425	--	--	--	--
E2	Buried 16 lb	150.0	100.0	2.2	2.0	0.67	200	370	305	10.7/19.5	10.0/80	1.61/1.79	1.46/1.50
B12	Surface	99.6	80.6	1.1	1.5	0.30	300	365	390	--	--	--	--
B11	Buried	91.0	80.9	1.9	1.8	0.45	285	450	480	--	--	--	--
B9	Buried	109.9	90.5	1.7	1.7	0.48	370	490	530	--	--	--	--

(Continued)

* Letter designation refers to A-155, B-105, C-4.2 mortar, and E-C24 explosive.

Table 5 (Concluded)

Crater No.	Placement Type	Crater Location X	Crater Location Y	Crater Dimension m E-W	Crater Dimension m N-S	Crater Dimension m Depth	Cone Index Data at Depth, cm 15	Cone Index Data at Depth, cm 30	Cone Index Data at Depth, cm 45	Moisture Content Percent	Moisture Content Depth, m	Density g/cm^3 Wet	Density g/cm^3 Dry
B10	Surface	90.8	90.2	1.3	1.2	0.28	225	405	455	--	--	--	--
B1	Surface	100.0	100.2	1.3	1.4	0.28	260	340	340	--	--	--	--
B2	Buried	91.0	100.2	1.8	1.6	0.50	290	315	445	10.7/17.7	10/70	1.51/1.73	1.36/1.47
E4	Surface	89.0	98.9	1.2	1.0	0.28	205	310	355	--	--	--	--
E5	Buried	75.0	98.7	1.3	1.6	0.45	245	305	350	8.1/22.2	10/70	1.81/1.81	1.67/1.48
B3	Buried	184.0	99.8	1.8	2.2	0.72	305	340	275	--	--	--	--
B4	Surfac	175.0	99.7	1.5	1.6	0.32	265	365	390	--	--	--	--
E3	Surface	84.9	89.0	1.7	1.8	0.50	185	330	485	--	--	--	--
E6	Buried	75.9	88.4	2.1	2.0	0.63	235	415	495	--	--	--	--
E7	Surface	68.0	100.0	0.9	0.8	0.20	195	250	330	--	--	--	--
E8	Buried	57.0	100.1	1.8	1.7	0.55	335	545	565	--	--	--	--
C6	Surface	183.7	80.4	0.7	0.8	0.25	245	330	305	--	--	--	--
C5	Buried	175.2	80.3	2.1	2.3	0.88	220	445	450	12.8/23.3	10/100	1.64/1.83	1.45/1.48
C3	Buried	175.1	90.1	2.6	2.5	0.95	230	345	225	--	--	--	--
C4	Surface	184.4	89.3	0.7	1.0	0.25	235	235	185	--	--	--	--
C2	Buried	50.0	100.0	2.0	2.0	0.68	440	650	700	13.2/20.0	10/100	1.46/1.82	1.29/1.52
C1	Surface	59.0	100.0	0.8	0.6	0.18	590	750+	750+	--	--	--	--
C8	Buried	62.5	91.1	2.0	2.4	0.65	275	455	400	--	--	--	--
C9	Buried	50.9	80.4	2.2	--	0.75	200	350	660	--	--	--	--
C10	Surface	40.4	77.0	0.7	0.4	0.13	510	675	750+	--	--	--	--
C7	Surface	44.5	89.8	0.7	0.4	0.16	460	645	620	--	--	--	--
E11	Surface	26.3	73.7	0.9	0.9	0.25	405	445	415	--	--	--	--
	4 lb												
E9	Surface	18.4	80.8	1.3	1.0	0.35	485	515	495	--	--	--	--
	10 lb												
E10	Buried	27.5	81.1	1.1	1.0	0.45	235	300	415	--	--	--	--
	5 lb												
E12	Buried	19.4	90.3	1.9	1.8	0.65	270	320	325	--	--	--	--
	8 lb												
C12	Buried	42.6	88.6	2.0	1.8	0.68	320	480	500	--	--	--	--

APPENDIX A: A PROPOSED SITE CHARACTERIZATION PROCEDURE FOR EXPLOSIVE DUST GENERATION

PART I: INTRODUCTION

1. This standard site characterization procedure (SCP) for battlefield obscurant evaluation has been developed from two sources: the WES's extensive field experience in explosive effects and its recent participation in several battlefield obscurant field tests. This experience is supplemented by other battlefield-related soil studies for trafficability and combat mobility. The procedure consists of three parts: (a) a pretest data set, (b) test observations, and (c) laboratory analysis. (Before discussing those in detail a brief rationale will be presented for the development of this procedure.)

Physics of Obscuration

2. In order to identify more clearly the nature of the requirement a brief consideration of the physical phenomena involved is helpful. The interaction of light or electromagnetic radiation with suspended particles in the air is referred to as scattering and is described by means of a scattering cross section denoted by σ . This cross section is a property of the constituent particles and varies with the frequency or wavelength of the radiation. The simplest law governing this interaction, known as Beer's law, is expressed as

$$I_\lambda = I_{o\lambda} e^{-N\sigma L}$$

where I_λ is the measured intensity of radiation of wavelength λ , transmitted through a path length, L , in air containing N particles per unit volume for an initial intensity $I_{o\lambda}$. Expressed in this form the law implies that no absorption occurs in the medium, that the particles are equal in size, uniformly distributed, and have the same cross sections. In practice some of these assumptions can be made; others

cannot. The principal modification that is necessary in practice is that which recognizes the variety of particle sizes. Thus, the cross section σ and concentration N become functions of particle diameter a . Expressing these features, Beer's law is now written

$$I_\lambda = I_{o\lambda} \exp \left[-L \int_{a_1}^{a_2} N(a)\sigma(a)\, da \right]$$

3. From this it is clear that the size distribution, N(a) , of the particles must be known, and a broad field of experimental physics is occupied with problems of this kind. In the atmosphere one encounters different forms of the function N(a) relating to smokes, fogs, ice crystals, rain, haze, and dust. In soils science still others apply to grain sizes. Frequently a generalized form of N(a) may be applied to several phenomena by appropriate changes in parameters. Such parametric forms are useful in simplifying computations. Their use, however, requires knowledge of the parameters and this provides the focus for experimental work.

4. Returning once more to Beer's law, it is necessary to mention that absorption cannot always be neglected and that a certain amount of scatter arises from molecules of the air itself. These are accounted for by expressing the cross section as a sum

$$\sigma = \sum \sigma_s \text{ (particles)} + \sum \sigma_A \text{ (particles)} + \sum \sigma_s \text{ (gas)} + \sum \sigma_A \text{(gas)}$$

in which s refers to scatter and A to absorption. Different species of molecules and mineral compositions of particles lead to different values for σ_A and σ_s and are indicated by the summation symbols which would be taken over species or type as appropriate. From this it can be seen that the mineral content and subsequent optical properties of the particulate material (and hence its soil origin in the case of battlefield obscuration) become necessary. It must be remembered that these optical properties are wavelength-dependent.

5. The issue is further complicated by suggesting that different mineral fractions may have different forms of N(a) and that gaseous by-products of explosives and engine fuels might be included in the molecular components. Note that particulate material especially on the battlefield is not likely to be uniformly distributed so that the exponential term in Beer's law must allow either an integral or summation over path length. The resulting expression when all these elements are included is generally not manageable. Finally, Beer's law itself is a simplified expression applicable only to relatively low attenuation conditions. The levels of obscurant concentration that arise on the battlefield make it necessary to consider interactions between scatterers (multiple scattering) and lead to more complex algorithms. These points are not primary concerns of the engineer but have been raised to illustrate the nature of the problems faced by the modeler and to indicate the context in which he will attempt to use terrain characterization data.

6. In characterizing the terrain for E-O systems, the engineer must be prepared to specify the sources of obscurant material as to mineral types, texture, or fines fraction and amount. In connection with the last item another major aspect of the obscuration problem is revealed--that of estimating the amounts of obscurant generated by certain activities and how they are distributed. It is this aspect of the problem that has occupied the major portion of the WES effort to date, and to better understand it a brief description of the mechanisms by which dust is generated is helpful.

Explosion Mechanics

7. The detonation of uncased explosives may be described for this purpose as the instantaneous release of a highly compressed and superheated gas. Three important effects are associated with the expansion of this gaseous envelope: the shock front, the kinetic energy transfer from the moving gas to the soil, and later the buoyant rise of the expanded envelope. The first two of these are active in the removal of

material to constitute the dust cloud, while the latter is related to the cloud development.

8. When cased munitions are used, the effects of rupturing the case and the resulting fragments must be included. Since the energy expended to rupture the case is mostly converted into the kinetic energy of the fragments, a large part will eventually be transferred to the soil to aid in the excavation and dust generation processes. However, the resultant dust may be distributed differently.

9. The placement of the explosive is also effective in determining the amount and distribution of the dust. Airbursts yield greater amounts of dust with little or no crater, depending on height. Subsurface bursts yield larger craters while confining the ejecta to exit angles more nearly normal to the surface. At sufficient depths dust amounts are reduced (but not necessarily eliminated) and vertical cloud growth may be restricted. This treatment will be confined to surface bursts.

Excavation process

10. For an uncased explosive charge located at the surface plane above a homogeneous soil the ejection of material results from the thrust of the expanding gas envelope acting downward and outward from the point of detonation. During the overpressure that accompanies the shock front the material in the surface layer is subjected to extreme shearing stresses. As the gases expand the surface is eroded downward and subsurface plastic flow develops.

11. Following the shock front and its associated overpressure, there occurs a rarefaction or underpressure, which aids the separation of particles from the surface. During the period of excess pressure there will be some reduction in the voids fraction due to compression, but that effect will be resisted by the skeletal structure. The remaining pressure burden will be compensated by an increase in air pressure in the cavities as air infiltrates the soil. As ambient pressure drops, the cavity air expands with the skeletal structure offering little resistance. As a result, particles are effectively separated and, at the surface, lifted into the air. The eroded material is ejected at

the rim of the growing crater in a direction roughly tangent to the wall. This ejected stream forms a conical sheet of increasing diameter and relatively constant angle as the crater expands.

12. As the kinetic energy transfer from the expanding gas to the soil increases, the mass flow increases but its velocity decreases. Tests show that ejection velocities are highest in the initial stages of crater formation. In the final stages of formation, the largest mass of material is slumped over the rim of the crater, a portion forming the lip and the remainder sliding back, partially refilling the crater. This material originates at the greatest depth and is the least representative of the dust. Most of the dust material originates on or near the surface and is probably deposited in the initial stages.

13. The crater that is observed is not the true excavation but the result of backfilling as mentioned and, depending on the soil, a certain amount of compaction. While it is probably possible to relate the dimensions of this apparent crater to the actual amount of material removed, it is not likely that the result would bear any relation to the amount of dust produced.

Dust cloud formation

14. Dust clouds arising from explosives are observed to consist generally of two parts. The first is the ejected material thrown out of the developing crater. This portion is immediately lifted by the buoyancy of the heated gases to form a columnlike feature. The second part is composed of material that is jarred loose from the surrounding surface by the shock wave and carried upward by turbulence. Because of its much lower exit velocity this material forms a lower feature sometimes referred to as the skirt and may extend outward to many times the crater diameter.

15. The separation of individual dust-sized particles from the soil mass is accomplished primarily by aerodynamic and barometric forces. The fundamental force resisting separation is the soil cohesion or electrical attraction between grains which is greatly aided by water. It is not expected that there is appreciable production of dust particles by the fracturing of larger grains except in very sandy soils.

Clearly then, the size gradation and water content of a soil are of primary importance in dust production.

16. These properties alone, however, cannot fully describe the cohesive strength. For moist soils the surface areas between grains hold water film by capillary action, hence the particle shapes, or more specifically their surface to mass ratios, become a factor. The ratios are partly dependent on the composition of the soil and partly on the soil's history. Cohesion in dry soils is due mainly to cementation and, hence, the water-soluble fraction of material. Thus, mineral and chemical composition and grain shapes are of interest. The cohesiveness may be obtained or at least inferred somewhat more directly by appropriate bulk measurements. One such measurement is the triaxial shear strength test. Another simpler test measures the Atterberg limits. A possible relation to cone index may be considered.

17. The effectiveness of interstitial air in causing separation during rarefaction should depend on the voids ratio (or porosity), which is obtainable from measurements of wet and dry densities and specific gravity. These measurements also yield moisture content.

18. The effect of vegetation in suppressing dust is fairly obvious. Less evident is the effect of root structure. Different root conditions, no doubt, will offer different resistance to blast effect. In any event, pulverized vegetation will add material to the dust cloud. Suggested measurements are organic content and root density. Note also that organic content affects the plasticity, hence cohesiveness, of the soil. Above the surface the stem densities for various plant types should be counted when practical, and types should be identified.

PART II: CHARACTERIZATION PROCEDURE

Preliminary Observations

19. The purpose of preliminary observations is to make a general assessment of the terrain and climate conditions and to collect data of a general nature that may aid in planning tests as well as analyzing their results. What one is concerned with here are vegetation, drainage features, predominant soil features, and any unusual or anomalous features that may affect tests. These results should be consulted in the final selection of test points. Recommended observations for this part are briefly described.

20. Visual and photographic observations of the site should focus on vegetation types, variety, and density. Surface conditions and variety should also be portrayed. When bare soil occurs in significant areas, its undisturbed condition as well as subsurface structure should be photographed or documented. Sod depth and root density can be documented by cutting a trench with a spade in vegetated areas and photographing the walls.

21. Terrain documentation should describe slope and landform in the test area and the drainage features should be discussed in detail. Geologic structures such as rock outcrops in the test area or nearby sources of alluvial material should be identified.

Quantitative Data Collection

Soils measurements

22. Bulk samples. Bulk samples of the soil representative of the entire test area should be collected. Since dust originates primarily in the surface layer, these samples should be taken mostly from the 0- to 15-cm-depth stratum. If stratification with different soil types occurs, at least one sample should be obtained from each stratum down to 75 cm. Surface samples should include roots but not foliage or deadfall material.

23. Cone index. Cone index measurements (U. S. Army Engineer Waterways Experiment Station 1962)* should be made at regular intervals throughout the test area. The instrument used is the cone penetrometer which consists of a proving ring attached to one end of a metal shaft with a calibrated metal cone at the other end. By means of a push plate on the ring the cone is forced into the soil to a depth of 45 cm while the dial gage of the proving ring is read at 5-cm intervals. The gage and ringe are calibrated to read out the force in pounds per square inch required to penetrate the soil.

24. Although CI has not yet been directly linked to dust occurrence, its relation to bearing strength is well established and with proper understanding should lead to a linkage. An important reason for seeking such a relation is the fact that cone index is easily obtained in the field in sufficient quantity to permit mapping of the sites. Cone index can also indicate subsurface structure.

25. Moisture content (MC). When time and conditions permit, a moisture survey of the site should be made by taking moisture measurements (U. S. Army Engineer Waterways Experiment Station 1962) at regularly spaced intervals, as with the CI data. This is more time-consuming and should be done only if the probability of rain occurring before the tests is very small. Measurements should be made in each soil type where stratification occurs and at the surface, otherwise with occasional measurements at 30- to 45-cm depth.

26. If MC is measured by means of a core sample, the same material may be used later for bulk testing. The core sample is obtained by pressing a metal sleeve of known weight and enclosed volume into undisturbed soil and carefully extracting it with the sample intact. After shaving off excess soil material at the ends of the sleeve, the soil may be pressed out into a sealable container for later weighing or may be weighed at once in the sleeve. It is important that moisture not be lost before this weighing occurs. The material must then be dried in an

---

* References cited in this Appendix are more fully identified in the References section at the end of the main text.

oven and weighed a second time. In this way both the wet density and dry density of the sample are obtained from which MC is computed. The used material may then be combined with others to provided a larger bulk sample for laboratory analysis. Moisture content can also be determined by using the Speedy Moisture Tester (Alpha Lux Company 1970).

Vegetation

27. Properties of vegetation that may be considered to influence the dust-producing properties of the soil are vegetation type, structure (U. S. Army Engineer Waterways Experiment Station 1968), and vigor. The characteristic of a plant probably bearing the most influence is the rooting structure of the plant, which varies with species, soil type, and climatic conditions. The primary form of a root is governed by growth characters of the species, but environment also plays a part in determining the form a root system takes. Such factors as water content, aeration, soil structure, and nutrients can bring about root modifications. Sometimes variation is so great that roots are scarcely recognizable as belonging to the same species. The roots function to bind the soil loosely or tightly, affecting dust production. Plants in vigorous condition would also tend to bind the soil more tightly than would dead or wilted plants.

28. Some plants have a dominant, deep taproot, while other plants form a fibrous network of small roots. The fibrous, shallow network would likely bind the soil more closely than would a single deep taproot.

29. The distribution of a certain type of plant over a given area can influence dust production. If a fibrous rooted plant such as a grass covers the area of interest, dust production would be less. Conversely, if plants were sparsely distributed over the same area, dust production might be nearly equal to that of a completely denuded area.

30. To sample the vegetation present, a quadrat should be laid off (Weaver and Clements 1938). A quadrat is a square area of measured size marked off for the purpose of detailed study. By the study of numerous quadrats a knowledge of vegetation structure may be obtained. The size of the quadrat is dependent upon the vegetation to be characterized. The 1-m quadrat is used in grassland and other herbaceous

vegetation, while in areas where plants are large and widely spaced, a quadrat of 100 m may be employed.

31. To quantify the effect of vegetation on dust production, quadrats are laid out in representative locations in the area of interest. Each species present is listed, described, and counted, and its approximate areal coverage noted. The approximate area of foliage species is estimated, i.e., square centimetre of leaf area per stem or plant. Root structure is noted and root counts may be taken. In the latter case the object will be to obtain a root density in terms of root stems per unit area of soil surface.

32. The biomass of the aboveground vegetation in the 1-m quadrat is determined by clipping the plants at ground level and putting the clippings in a plastic bag for later determination of wet and dry weights in the laboratory. A trench 1 m long along the boundary of the quadrat is then dug. This excavation shows the configuration of roots below ground level. A depth of 0.5 m is usually sufficient to include the roots of most herbaceous plants. A sketch should be made to illustrate the nature of the root structure, and a photograph showing a scale indicator such as a metre stick should be made of the exposed roots. To obtain a more quantitative measure of root biomass, the organic content with depth should be determined. A core sample should be taken to the depth of the deepest root. Ten-centimetre sections of this case should be separately bagged for laboratory determination of organic content by depth.

In-test Observations

33. The object here is to sample the soil at the point of testing under the conditions that exist at the time of the test. If the test occurs at a previously sampled grid point and no rain or other change has occurred, only those data not already obtained need be taken. Otherwise, density, MC, and CI measurements could be repeated--MC at the surface and at the 30- to 45-cm depth, and CI at three points separated by at least 0.5 m around the test site. A bulk sample should be obtained

for analysis of organic content, size gradation, and Atterberg limits.

34. After the dust event it is necessary to assess the nature and extent of the disturbance of the soil. If explosive events are involved, this will include crater measurements. For vehicle tests the area of disturbed soil as well as depth should be measured or estimated. The object is to determine the mass or volume of soil that has been displaced.

35. Location of the disturbed area is recorded mainly for purposes of correlation with the photographic documentation. This may be done with a surveyor's chain or steel tape if suitable reference marks exist. If references are too far away, a transit and rod may be necessary.

36. The crater diameter is measured in two directions at right angles. In the case of artillery burst, these are along and transverse to the firing axis. The diameter is measured at the intersection of the crater wall or its extension and the original surface line. Depth is measured from the original surface level to the visible or apparent crater floor (top of fallback material). For small craters this is easily done by laying a rod or straight beam across the crater and scooping away rim material to allow the ends to rest at the original surface line. For larger craters a transit and rod may be necessary to measure the depth; in this case, care should be taken to assure that the rod does not compress the material at the bottom.

37. For large or irregular craters, profile data give the best results. Profiles are measured by means of either the horizontal beam or the transit and extend beyond the lip material. They are taken at right angles with the point of intersection noted on each and measurement is to the visible crater surface. Spacing of the individual readings must be carefully maintained to allow accurate reconstruction.

PART III: LABORATORY ANALYSIS, POSTTEST MEASUREMENTS

38. Laboratory analysis is performed on the bulk samples collected in the field and may also include the material from the density samples. The most important result is the size gradation, especially the percentage fines below 100-μm diameter. If possible, the shape of the gradation curve from 1-100 μm is desired. Usually these are obtained by successive sieving, followed by sedimentation analysis of the residual fines, but other methods exist. Where clay samples tend to agglomerate in the sedimentation process, it has been necessary to use electron micrographs to obtain gradation of the fine residue.

39. For sieving, a sample of known dry weight approximately 250 g is first washed in a fine mesh sieve (No. 200) until all of the water-soluble fraction and fines are removed. After drying and reweighing to determine the loss, the sample is placed in a stack of graduated sieves and shaken to allow separation and weighing of successive size fractions. The weight of the portion lost in washing is taken as that of the fines less than 0.074-μm diameter (No. 200 sieve), and it is assumed that water-soluble material is of negligible weight. If it is expected that appreciable water-soluble material exists in a sample, the fine solids may be weighed separately after washing by the use of filter paper in the washing process.

40. After sieving, the fine material (passing No. 200 sieve) is further graded by a sedimentation process. This consists of placing the fine material in suspension in a suitably prepared container of water and measuring the specific gravity of the mixture using a hydrometer at measured time intervals. As particles settle out of suspension, the loss of mass is computed from the change in specific gravity. Stokes' law is applied to establish the sizes corresponding to the measured times. For further details of these tests refer to Engineer Manual 1110-2-1906, Laboratory Soils Testing.

41. The determination of the Atterberg limits--plastic limit (PL) and liquid limit (LL)--requires a sample of approximately 500 g. The test is performed on the fraction of this sample passing a No. 40 sieve.

The LL is determined by wetting the sample, placing a measured amount on a specially designed apparatus, marking a groove in the specimen, and subjecting it to a series of measured blows while observing whether the groove closes. The material is allowed to dry partially and the test repeated. At each repetition the moisture content is determined and the value at which the groove is found to close after a prescribed number of blows is the LL.

42. For the PL the sample is further dried, and at successive stages a 1/8-in.-diameter bead rolled out on a flat plate. The MC at which separation of the bead occurs under this process is taken as the PL. Both of these tests must follow carefully prescribed procedures at every step; details may be found in the above-referenced manual.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Mason, James B.
Site characterization for the MBCE/DIRT II battlefield environment tests / by James B. Mason and Katherine S. Long (Environmental Laboratory, U.S. Army Engineer Waterways Experiment Station). — Vicksburg, Miss. : The Station ; Springfield, Va. ; available from NTIS, 1981.
51 p. in various pagings : ill. ; 27 cm. -- (Miscellaneous paper / U.S. Army Engineer Waterways Experiment Station ; EL-81-8)
Cover title.
"September 1981."
Final report.
"Prepared for Army Atmospheric Science Laboratory, U.S. Army Development and Readiness Command."
Reference: p. 32.

1. Environmental impact analysis. 2. Explosives, Military. 3. Munitions. 4. Terrain study (Military science). I. Long, Katherine S. II. U.S. Army Atmospheric Sciences Laboratory. III. U.S. Army

Mason, James B.
Site characterization for the MBCE/DIRT II : ... 1981.
(Card 2)

Engineer Waterways Experiment Station. Environmental Laboratory. IV. Title V. Series: Miscellaneous paper (U.S. Army Engineer Waterways Experiment Station) ; EL-81-8.
TA7.W34m no.EL-81-8